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Automated Train Operations (ATO) Safety and Sensor Development

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14. ABSTRACT
The goal of the Automated Train Operations (ATO) Safety and Sensor Development Project was to define system requirements for a locomotive-borne sensor platform (SP) to support the ATO concept. Transportation Technology Center, Inc. conducted market research to gain an understanding of available commercial off-the-shelf (COTS) sensor technologies that may be leveraged by SP. Safety efforts of this project focused upon the hazards addressed by SP and regulatory requirements that may apply to SP.

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Automated train operations, ATO, sensor platform, SP, locomotive onboard sensor platform, locomotive-borne sensor platform, autonomous, train, sensors, train control

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

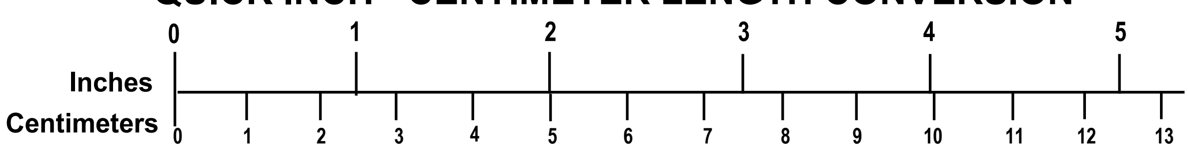
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

From September 2018 to September 2019, the Federal Railroad Administration (FRA) supported Transportation Technology Center, Inc. in developing requirements and initiating the safety analysis for a locomotive-borne sensor platform (SP) to support automated train operations (ATO). The key deliverable of this effort is a draft SP functional and performance requirements specification, included as an appendix to this report. The team also conducted market research of sensor technologies that may support an ATO SP at the Transportation Technology Center in Pueblo, CO.

Under this project, researchers conducted the following tasks:

- Developed requirements for a locomotive-borne SP intended to support the sensing of risks associated with the environment in which an ATO train is operating
- Conducted market research to identify any commercial off-the-shelf (COTS) sensor technologies that may perform the required functions with no or minor modification
- Progressed a safety assessment of the ATO SP concept including initiating a preliminary list of hazards, SP safety requirements, and SP developer guidance

The SP requirements define functional and performance characteristics necessary for the SP to detect, classify, and track hazards ahead of a train. The requirements were derived through a review of the SP concept of operations (CONOPs), ATO system requirements, and ATO onboard segment requirements. Capturing and further decomposing the requirements related to SP led to the development of a definition of the SP as a system at each level.

Researchers conducted market research to identify COTS sensor technologies most likely to be utilized in support of ATO, and investigated sensors and sensor systems (i.e., sensors coupled with additional computational hardware). Market research found that there are numerous sensors and/or sensor systems available on the commercial market with a wide array of performance parameters, including: visual spectrum electro-optical, infrared electro-optical, Light Detection and Ranging (LIDAR), Radio Detection and Ranging (RADAR), and temperature sensors. As performance of a given technology increases, so does the overall cost of the sensor/sensor system. Selecting the technologies to be incorporated into a sensor platform design was out of scope for this project.

The safety assessment focused on developing a preliminary understanding of the potential hazards of the SP. The creation of the preliminary hazard list used a review of the SP concept and regulatory requirements that may apply to the SP, specifically, Title 49 Code of Federal Regulations (CFR) Parts 229 and 236. This hazard list will provide the foundation for the derivation of a draft set of SP safety requirements, which was also initiated on this project. The draft SP safety requirements are expected to grow and/or be modified as the overall ATO system safety assessment progresses.

Additionally, the SP safety analysis efforts identified the need for an SP developer's guide that provides information to potential SP system developers regarding the various safety assurance processes and tests that must be performed to meet the safety objectives of the industry. While this effort was begun during this project, the SP developer's guide, as well as an overall ATO system developer's guide, is being completed under a separately funded FRA project.

1. Introduction

In 2018, the North American railroad industry initiated a program to define the concept and requirements for interoperable automated train operations (ATO). The Federal Railroad Administration (FRA) is supporting this industry effort by funding research projects that are related to and support the development of ATO.

ATO is not a monolithic or standalone system, but rather a method of operation supported by the functions and interaction among Interoperable Train Control-Positive Train Control (ITC-PTC), ITC-Energy Management System (ITC-EMS), and ITC-ATO support systems (ITC-ATOSS). The term ATO system of systems (SoS) is used to define the collection of these systems that perform the functions necessary to support the interoperable ATO method of operation. Figure 1 illustrates the primary triad of independent ITC systems that comprise the ATO SoS.

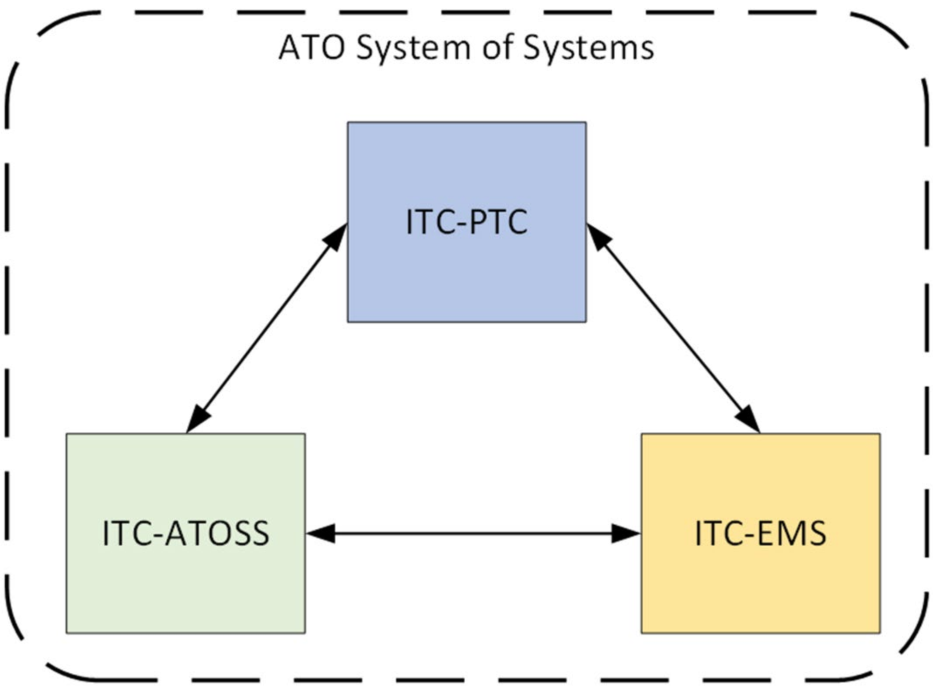

Figure 1. Primary Triad of the ATO SoS

Within the ATO SoS:

- ITC-PTC is a system that performs train control functions by enforcing mandatory directives such as limits of movement authorities, civil speed restrictions, temporary speed restrictions, work zone limits, and critical alerts.
- ITC-EMS performs motion control functions by interacting with locomotive control systems to move the train within the limits defined by that train's mandatory directives.
- ITC-ATOSS monitors the operating environment of the train and initiates appropriate train response(s) to hazardous condition(s).

ITC-ATOSS monitors the internal and external operating environment of the train and initiates appropriate train responses to operating conditions typically performed by an onboard train crew until the condition has been resolved. To initiate the appropriate train response, the ATOSS onboard (OB) segment provides hazard condition data to the ITC-PTC OB segment to initiate/enforce train responses (e.g., train stops, speed restrictions). For hazardous conditions that additionally require non-PTC enforceable responses (e.g., locomotive horn, bell, headlights, and ditch lights), the ATOSS OB segment interacts directly with locomotive control systems to perform the necessary functionality (e.g., horn sequencing, turning the bell off, and flashing ditch lights).

Table 1 provides a description of the external and internal conditions monitored by the ATOSS.

Table 1. ATOSS Condition Categories

Condition Category	Description
External conditions	External conditions include conditions within the environment ahead of and around the lead locomotive of the train. ATOSS monitors this region which includes the foul volume, track and road structures including bridges and tunnels, and right-of-way. ATOSS monitors these regions to initiate the appropriate train response for conditions that present hazards, such as track obstructions and people encroaching within the foul volume (i.e., Objects of Interest [OOI]); as well as the state of specific objects such as the activation state of crossing protection systems and alignment of switches (i.e., Condition of Interest [COI]).
Intra-train conditions (InTC)	InTC are within the locomotive and train such as a failed horn, failed bell, pneumatic control switch (PCS) indication, and hazardous motion control-related conditions (e.g., excessive in-train forces and depletion of air brake charge state). ATOSS monitors locomotive control systems to detect InTCs and initiate the appropriate train response.

The ATOSS OB segment (i.e., ATOSS components located onboard the train) is further decomposed into additional subsystems and components to perform the functions needed to monitor the operating environment of the train to initiate an appropriate train response to a hazardous condition. Figure 2 illustrates the additional decomposed sensor platform ATOSS OB segment subsystems and components and Table 2 describes it, respectively.

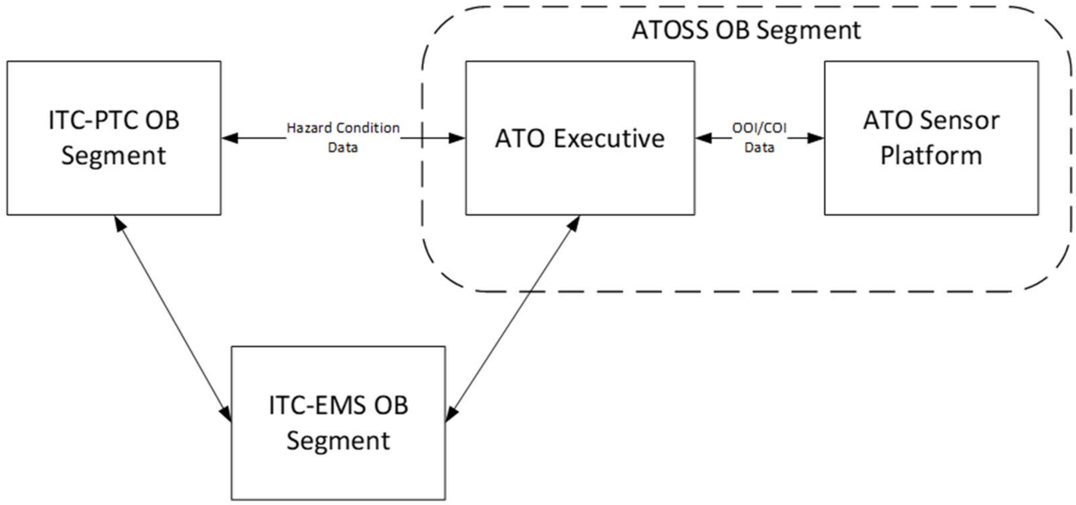

Figure 2. ATOSS OB Segment Subsystems/Components

Table 2. ATOSS OB Segment Component Description

ATOSS OB Segment Component	Description
Automated Train Operations Executive (ATO Ex)	ATO Ex processes data from peripheral ATOSS OB components and SP to provide hazardous condition data (e.g., specific hazardous condition and condition location) to the ITC-PTC OB segment to initiate an appropriate train response.
Sensor Platform (SP)	The SP is a set of sensors mounted on the locomotive that monitors the external environment ahead and around the lead locomotive and performs a set of processes to provide actionable OOI- and COI-related data (e.g., object classification and object position) to the ATO Ex.

In 2018, FRA funded Transportation Technology Center, Inc. (TTCI) to:

- Define functional system requirements for a locomotive-borne sensor platform to support ATO
- Perform market research on suitability of commercial-off-the-shelf (COTS) sensor products to meet the needs of the SP
- Initiate analysis of ATO SP safety, to the extent possible with available funding

The requirements development portion of this project was limited to defining interoperable functional and performance requirements of a SP to monitor the external environment ahead of and around the lead locomotive to provide actionable OOI/COI data to the ATO Ex.

1.1. Objectives

The objectives of the ATO safety and sensor development project were to:

- Define functional system requirements for a locomotive-borne sensor platform to support the ATO concept
- Identify available COTS sensor technologies that could perform the required SP functions to support ATO
- Progress safety assessment of the ATO SP concept

1.2. Overall Approach

As part of the broader industry ATO system development effort, researchers formed an ATO advisory group (AG) and technical working group (TWG) comprised of US freight and passenger railroad operational experts. The AG's role is to provide guidance regarding the high-level strategic needs of ATO. The AG members participate in periodic conference calls and/or face-to-face meetings and make decisions regarding the required functions that should be included in the ATO system, as well as the SP. The TWG's role is to provide technical guidance and subject matter expertise on the various systems being integrated to provide ATO functionality. The TWG participates in monthly conference calls and/or face-to-face meetings focused on various aspects of the ATO system (e.g., the SP) and the development of requirements. Additionally, in support of this project, the TWG reviewed draft requirements, providing comments to better define the function and performance needed from the sensor platform. The research team worked with both groups to progress the project, seeking guidance related to stakeholder requirements.

To assist in the development of SP functional and performance requirements, the authors contracted a sensor systems consultant providing technical guidance regarding the various functions that may be performed by sensor technologies. Additionally, the team contracted a systems safety consultant to progress the overall SP system safety assessment.

1.3. Scope

The ATO safety and sensor development project effort consisted of the following:

- Development of SP functional requirements
- Development of SP performance requirements
- Market research focusing on COTS sensor technology
- Initiation of high-level SP safety analysis efforts

The scope for this project included:

- Developing requirements for a locomotive-borne sensor platform intended to support the sensing of risks associated with the environment in which an ATO train is operating
- Conducting market research to identify any COTS sensor technologies that may perform the required functions with no or minor modification

- Progressing a safety assessment of the ATO SP concept including initiating a preliminary list of hazards, SP safety requirements, and SP developer guidance

Once approved by the project the AG, the Interoperable ATO Onboard Sensor Platform definition documentation—produced in this project with FRA funding—will be delivered to the AAR for possible inclusion in the AAR Manual of Standards and Recommended Practices (MSRP). Publication of Interoperable ATO Onboard Sensor Platform requirements documentation within the AAR MSRP is out of scope of this effort and is at the discretion of the AAR.

1.4. Organization of the Report

This is a summary report that highlights the results of the SP project. The organization of the report is as follows:

- Section 1 provides background information on the project to aid in setting the context for the work performed.
- Section 2 reviews the results of the work performed.
- Section 3 describes the results and recommended future phases for the development of SP requirements.
- Appendix A contains the SP requirements document.
- Appendix B list the identified but undefined parameters.

2. ATO Safety and Sensor Development Tasks

The ATO Safety and Sensor Development Project was divided into three main tasks. These tasks included development of SP requirements, conducting market research to identify COTS sensor technologies that could satisfy the requirements of an SP, and initiating SP safety analysis efforts.

2.1 Timeline of Key Events and Development Decisions

Table 3 shows the timeline of the ATO Safety and Sensor Development Project.

Table 3. Key Requirements Meetings

Date	Event	Topic
June 18, 2019	TWG Meeting	SP concept review
September 11, 2019	TWG Meeting	SP functional review
December 3, 2019	AG Meeting	SP architecture review
June 26, 2020	AG Meeting	Review of approaches for decomposition of SP system requirements to define SP architectural framework components to promote operational, use, and maintenance consistency

Table 4 shows the key decisions made by the AG and/or TWG regarding the development of SP functional and performance requirements.

Table 4. Key Requirements Development Decisions

Date	Description
June 18, 2019	SP shall detect track conditions that are hazardous to train movement along the route (i.e., ballast washout and thermal buckling), but the SP is not expected to identify track defects that do not present an immediate hazard to train movement (i.e., SP not expected to perform track inspection).
September 11, 2019	SP shall detect track conditions that are hazardous to train movement along the route (i.e., ballast washout and thermal buckling), but the SP is not expected to identify track defects that do not present an immediate hazard to train movement (i.e., SP not expected to perform track inspection).
	SP shall detect snow at or above top of rail. Identification of depth may be required.
	SP to detect water above top of rail. Identification of depth is not required.
	SP to detect rock, soil, or other materials on rail. SP is not expected to measure depth of material over rail.
	SP is expected to use non-contact sensors to detect collision.
December 3, 2019	SP to detect and classify vehicles as an OOI. SP is not required to determine the type of vehicle (i.e., motorcycle, car, bus, truck, and other).
	Confirmation that scope of SP definition is limited to identifying objects or conditions posing an immediate hazard to the operation of the train
	SP performance requirements may be defined based on operational performance of trains.
June 26, 2020	SP functional and performance requirements must be decomposed further to promote industry needs for operation, use, and maintenance commonality.

2.2 ATO Sensor Platform Requirements Development

The function of the SP is to provide high confidence, accurate, non-spurious, and actionable information to other ATO onboard subsystems regarding the presence or absence of environmental hazards ahead of the train.

Researchers reviewed the initial drafts of the ATO system ConOps and ATO onboard segment requirements to determine system objectives and/or segment requirements that should be satisfied by the SP. These objectives represented a high-level list of functions that SP must be able to perform to satisfy the operational and safety needs of the ATO system.

The requirement of the onboard SP is to monitor the environment ahead of the train to identify the existence of hazards to the train or train movement. The location of hazards with respect to the path of the train must be determined to allow for the prioritization of objects that have been detected in the environment ahead. Three areas of interest were defined as follows:

1. **Foul Volume**: A three-dimensional space along the centerline of track, extending ahead of the train to be determined (TBD) feet, along the train's intended route, within which objects have a high probability of presenting a hazard to the train. Figure 3 shows an illustration of foul volume.

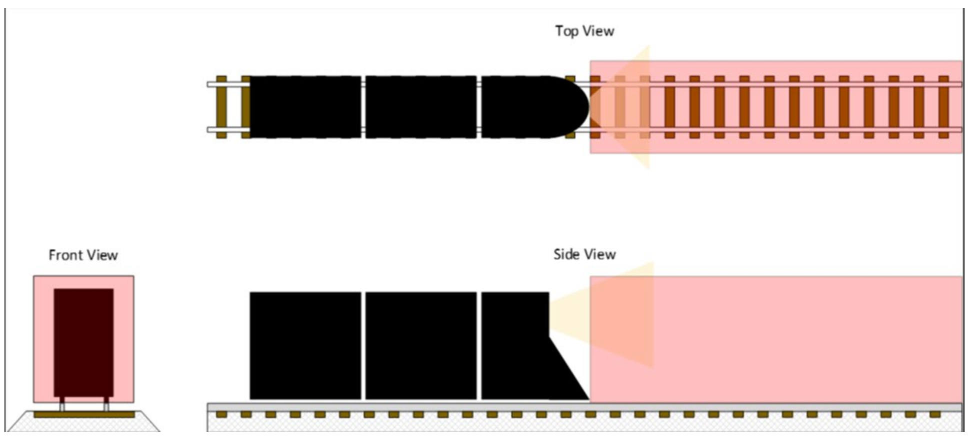

Figure 3. Foul Volume

2. **Right-of-Way (ROW)**: The area not included in the Foul Volume, i.e., the region of space extending to the left, right, and above the Foul Volume. The extent of the ROW to the left and right of the Foul Volume will be a set, constant value which will be determined through future safety assessments.
3. **Track and Road Structure**: The track area includes features of the railroad track such as rail, ties, ballast, and the roadbed. The structure area also includes features of the railroad track a train traverses such as bridges and tunnels. Figure 4 shows an illustration of the track and road structure.

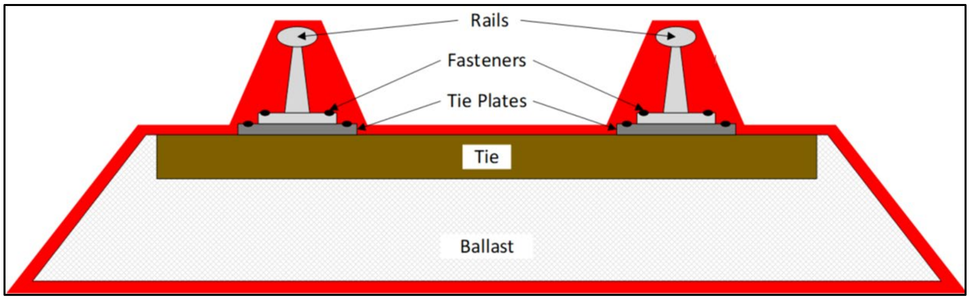

Figure 4. Track and Road Structure

Detected hazards were broken down into two main categories: objects of interest and conditions of interest.

The definition of an object of interest is the following:

1. An object within the foul volume ahead of a train that presents a collision hazard.
2. An object in the ROW that may move into the foul volume and present a collision hazard to the train.
3. A person or vehicle in the ROW.
4. An object in the foul volume of an adjacent track that presents a collision hazard to a train operating on the adjacent track.

Conditions of interest encompass both environmental and systemic conditions that may negatively affect the safe operation of a train. From an environmental standpoint, conditions of interest are such things as misaligned switches, water above the top of rail(s), and missing or washed out ballast. Systemic conditions of interest include degraded performance of a sensor or sensors because of poor weather conditions (e.g., heavy fog, rain, snow, excessive glare from the sun, and low light conditions). Additionally, they may degrade performance of the data processing functions of the SP.

Freight train stopping distances can be a mile or more depending on many factors such as initial train speed, grade, and total trailing tonnage. Coupled with the natural obstructions from the terrain and track curvature, it is unlikely that an onboard sensor platform can be developed to reliably detect objects of interest and conditions of interest at a sufficient distance to bring a train to a stop in all scenarios where a train is travelling at track speed. However, in restricted speed operation, trains are expected to be able to stop short of an obstruction regardless of conditions.

Title 49 Code of Federal Regulations (CFR) § 236.812 defines restricted speed as:

> "A speed that will permit stopping within one-half the range of vision, but not exceeding 20 miles per hour."

Determining the proposed SP minimum object of interest detection range TBD value occurred through a combination of computer simulation and statistical analysis. Using a Monte Carlo simulation process, researchers analyzed 20 combinations of consists and grades. The combinations were chosen due to the expected poor braking performance. These configurations represent what may be considered the "worst-case scenario" when it comes to train stopping distance: heavy train consists traveling on varying degrees of downhill grades. These consists are at the limit of weight and downhill grade allowed by operating procedures. The Monte Carlo simulations focused on the trains stopping distances, starting from an initial velocity of 20 mph, and an initial brake setting ranging from 0 to 10 psi depending on the downhill grade. For each of the 20 configurations, 100 separate Monte Carlo simulations were conducted. Table 5 lists the 20 configurations simulated, as well as their initial conditions.

Table 5. Simulated Restricted Speed Stopping Distance Train Consists

Train Type	Empty/Loaded	Braking Type	Grade	Initial Train Velocity (mph)	Brake Set
Intermodal long	Loaded	Distributed, front and rear	-1.1% grade	20	None
Intermodal medium	Empty	Head end	-0.5% grade	20	None
Intermodal medium	Empty	Head end	-1.1% grade	20	None
Intermodal medium	Loaded	Head end	0% grade	20	None
Intermodal short	Empty	Head end	-2.8% grade	20	None
Intermodal short	Loaded	Head end	-2.2% grade	20	None
Manifest 100 cars	Mixed	Head end	0% grade	20	None
Manifest 100 cars	Mixed	Head end	-0.5% grade	20	None
Manifest 100 cars	Mixed	Head end	-2.2% grade	20	10 psi pressure reduction
Manifest 150 cars	Mixed	Distributed, front and rear	-1.7% grade	20	6 psi pressure reduction
Manifest 150 cars	Mixed	Distributed, front and rear	-2.2% grade	20	10 psi pressure reduction
Manifest 200 cars	Mixed	Distributed, front and rear	0% grade	20	None
Unit 100 cars	Loaded	Head end	0% grade	20	None
Unit 100 cars	Loaded	Head end	-1.1% grade	20	6 psi pressure reduction
Unit 135 cars	Loaded	Distributed, front and rear	-1.7% grade	20	10 psi pressure reduction
Unit 200 cars	Loaded	Distributed, front and rear	0% grade	20	None
Unit 200 cars	Loaded	Distributed, front and rear	-0.5% grade	20	None
Unit 200 cars	Loaded	Distributed, front and rear	-1.1% grade	20	6 psi pressure reduction
Unit 260 cars	Loaded	Distributed, middle	0% grade	20	None
Unit 260 cars	Loaded	Distributed, middle	-1.1% grade	20	6 psi pressure reduction

Each of the 100 trials of the Monte Carlo simulation for each of the 20 configurations was further analyzed for trends in stopping distance to determine an accurate worst-case stopping distance. The mean stopping distance, stopping distance standard deviation, and stopping distance probability distribution was determined for the 100 trials. From this data, the worst performing configuration was a 135-car unit train with distributed power on a 1.7 percent downhill grade with an initial brake pipe pressure reduction of 10 psi. Figure 5 shows the statistical analysis of this consist.

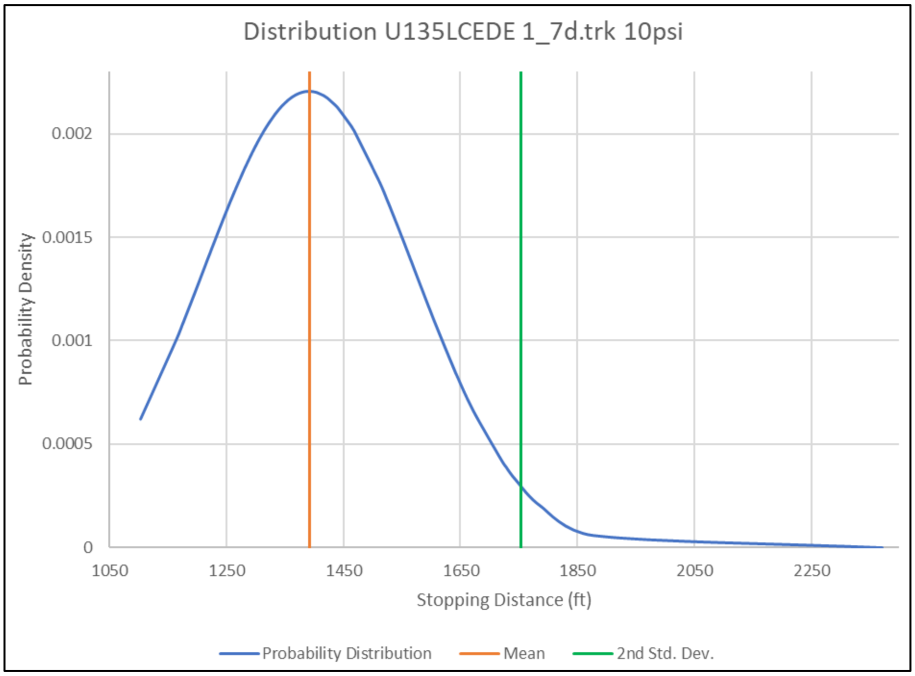

Figure 5. Stopping Distance Distribution for Monte Carlo Simulation

The mean stopping distance of this train over the 100 Monte Carlo trials was 1,392 feet, with two standard deviations at 1,753 feet. For the performance requirement TBD at a minimum object detection range value, the value was extended past the second standard deviation to a round number of 2,000 feet, then doubled to arrive at the recommended TBD value of 4,000 feet. The doubling of 2,000 feet is from the operating rule that a train at restricted speed must be able to stop within one-half of the sight distance.

The arrived at TBD value is an estimation based on real-world operational scenarios and their computational simulation. Later development of the SP may find this distance to be too great to meet the stringent safety requirements and unfeasible with current sensor technologies.

As the development of ATO requirements progressed, a concern was raised by the AG and TWG regarding the commonality of function with respect to the SP. An initial requirement of ATO is that, like ITC-PTC, ATO must be interoperable. Broadly speaking, “interoperable” means that a system owned by one railroad must be able to properly function on another railroad.

A primary stakeholder requirement for the SP is that it too is interoperable. However, the current concept of interoperable allows for a system that “works” across all railroads but does not necessarily have a high degree of commonality of operational performance, use, and maintenance across all railroads. System level requirements that define a minimum set of functional and performance requirements for the SP allow a developer to design a system in any way they see fit provided that design meets all minimum requirements. The AG provided direction that the SP must have a high degree of operational performance, use, and maintenance commonality across all railroads.

To accommodate this need, there is a need for a further decomposition of the SP system level requirements. This additional decomposition will define various functions and aspects of the SP in greater detail. This level of requirements decomposition was out of scope for this project.

2.3 Market Research

The research team conducted market research to gain an understanding of available COTS sensor technologies that may be leveraged by the SP. Market research consisted of a search for publicly available information on sensor types, sensor systems, and sensor components that could be procured to best meet the SP requirements. Complete COTS sensor systems (e.g., military sensor platforms and aviation sensor platforms) are often geared toward applications outside of the railroad environment and can be proprietary, costly, and would require significant alteration to support the SP requirements. This would make the procurement of such sensor systems cost-ineffective, and as a result, the strongest emphasis of the market search was on sensor components and their capabilities.

Market research is separated by sensor type. These categories encapsulate nearly all sensors applicable to the SP. Discussion of specific manufacturer name and product cost have been purposefully omitted. Table 6 through Table 13 use the "$" symbol to indicate estimated relative cost. The cost estimations are relative to the lowest end performance technology in each table category and are independent of the other categories.

2.3.1 Visual Spectrum Electro-optical

Image and video streams of the outside environment provide information-dense streams of data. Today's high-resolution image sensors, coupled with their high frame capture performance, means that a high volume of information about the environment is encoded within their outputs for later processing; hence, the term information-dense. Higher frame capture sensors provide greater volumes of data for analysis via algorithm. Locomotives operating at 60 mph cover roughly 88 feet per second. High frame-capture rates can reduce the distance that a locomotive travels between acquired frames, increasing the temporal resolution of the data. Still, there is an engineering tradeoff between sensor resolution and frames-per-second (fps) processing output, which must be considered. Higher resolution sensors see a lower fps performance, and vice-versa. Visual spectrum electro-optical sensor cameras can be negatively impacted by rain, snow, dust, or any other object that obstructs the lens.

The pixel resolution of image sensors is measured by the total number of pixels on the imaging sensor, often on the order of millions of pixels, or megapixels (MP). Assuming an image sensor with a static field of view (FOV), the greater the pixel resolution, the greater the spatial resolution possible. Spatial resolution refers to how close two objects can be to one another and still allow the image sensor to accurately resolve them as separate objects. This is critical in object detection and classification tasks. High spatial resolution is desired for SP purposes. High pixel resolution sensors have a greater cost.

Modern charge-coupled device (CCD) visual spectrum sensors capture three bands of light in the electromagnetic spectrum: generally, the red, green, and blue (RGB) light bands. Monochromatic (i.e., black and white or grayscale) configurations exist which only capture the total light intensity of incoming light with no spectral context. Red, green, and blue light is absorbed at different levels by every object, which means that every object also reflects RGB light differently. RGB sensors have higher spectral resolutions, communicate more data about objects in the field-of-view, and are therefore more desirable. Table 6 lists several COTS visual image sensors, their specifications, and relative cost.

Table 6. Visual Spectrum Electro-Optical Device Performance Parameters

Product Type	Resolution	Frames per Second	Unit Cost
CCD Image Sensor Mono	50.1 MP	4	$$$
CCD Image Sensor RGB	50.1 MP	4	$$$
CCD Image Sensor RGB	47 MP	7	$$$$
CCD Image Sensor Color	25 MP	53	$$$
CCD Image Sensor RGB	13 MP	30	$

Image capture supports object detection and classification because the data from these sensors contains information about object shape and size. Binocular image capture also supports object ranging and object localization for tracking. Depending on the binocular configuration and sensor image resolution, optical sensors can be used to range objects on the order of miles, or in close proximity.

2.3.2 Thermal Imaging Cameras

Thermal cameras provide information-dense data about the environment in addition to temperature context. Temperature signature supports detection and identification of fires, operating vehicles, machinery, people, and animals ahead of the locomotive. Binocular configurations of thermal cameras may also be used to obtain range information for distant and nearby objects. Thermal cameras can be negatively impacted by rain, snow, dust, or any other object that obstructs the lens.

Thermal cameras operate in the far-infrared portion of the electromagnetic spectrum. Thermal cameras are fundamentally image sensors; therefore, they share similar performance parameters and engineering tradeoffs as the visual spectrum cameras covered in Section 2.3.1. Thermal cameras generally have lower fps and resolution performance compared to visual spectrum cameras, but they provide useful information that visual cameras cannot. Thermal cameras have an inherent limit to the temperature range they are able to detect before saturating. The larger the detectable temperature range of a sensor, the higher its expected cost. Modern vanadium oxide thermal sensors also dissipate a high amount of heat, and generally require active cooling measures. These factors are inherent to thermal camera physical design and will have to be considered when sourcing COTS products. Table 7 lists several COTS infrared sensors, their specifications, and relative cost.

Table 7. Thermal Camera Device Performance Parameters

Product Type	Resolution	Frames Per Second	Operating Temp	Unit Cost
Thermal Image Sensor	160 × 120	8.7	- 10 °C ~ 80 °C	$
Uncooled VOx Microbolometer	640 × 512	60	- 40 °C ~ 80 °C	$
Uncooled VOx Microbolometer	1024 × 768	30	- 40 °C ~ 71 °C	$$
Uncooled VOx Microbolometer	1920 × 1200	60	- 40 °C ~ 65 °C	$$$

2.3.3 Infrared Cameras

Infrared cameras generate imagery by capturing infrared light in the near-infrared (i.e., roughly 700 nm to 900 nm wavelength) part of the electromagnetic spectrum. This gives images several unique properties potentially beneficial to the SP. The near-infrared range of light has a strong propensity to reflect from foliage. This strong reflection creates a strong response from infrared cameras to foliage, which may benefit processes that discriminate objects of interest from plants and trees that contribute to image clutter. Another useful property of infrared camera images is that the sky appears very dark due to properties of atmospheric light scattering. This atmospheric scattering effect cuts through atmospheric haze and allows for more clarity under water as less light from the sky reflects off the water's surface. With the use of active illumination, infrared light sources can be used to illuminate a dark/nighttime environment allowing an infrared camera to effectively "see" in the dark. These benefits, unique to infrared cameras, are included with their general ability to discern object shape and size for detection and classification, as well as ranging distant or nearby objects when in a binocular configuration. These cameras are generally negatively affected by weather conditions which may obstruct the camera lens, still but may be better suited to see in certain weather conditions (e.g., falling snow and rain) in which infrared light passes through more easily. Table 8 covers several infrared cameras, their specifications, and relative cost.

Table 8. Infrared Camera Device Performance Parameters

Product Type	Resolution	Frames per Second	Unit Cost
Infrared Camera	640 × 515	119	$$
Infrared Camera	640 × 512	475	$$$
Infrared Camera	1280 × 1024	119	$$$
Infrared Camera	640 × 512	220	$$$

2.3.4 Spectral Imaging Cameras

The previously covered sensor technologies create images by capturing light from very narrow bands of the electromagnetic spectrum; near-infrared band for infrared cameras, far-infrared band for thermal cameras, and RGB visual spectrum bands for standard cameras. Spectral imaging cameras leverage specialized optical sensors that can create an image using any desired combination of bands from the electromagnetic spectrum.

Each pixel of a spectral imaging camera sensor is sensitive to bands of the electromagnetic spectrum beyond the visible and infrared bands. This gives spectral imaging cameras vastly superior spectral resolution compared to other types. Spectral resolution data provides great detail about the composition of objects. Every object, whether biological, metallic, wood, or other, reflects light in a unique way indicated by the spectral properties of the reflected light. Spectral imaging cameras with high enough spectral resolution can determine the composition of objects at a distance. This property of spectral imaging cameras offers the potential for improved differentiation of objects of interest from clutter over visible light or infrared cameras alone.

Spectral cameras fall into two main categories: multispectral and hyperspectral. Multispectral imaging cameras generally capture only a few bands of the electromagnetic spectrum; therefore, their spectral resolution is relatively low. They may capture the standard RGB visual bands as well as near and far infrared bands to aid in object detection, for example. Hyperspectral imaging cameras aim to capture as many bands of the electromagnetic spectrum as possible to paint a complete picture of the spectral properties of incoming light. Information about object composition can be inferred at every location of an image captured by hyperspectral cameras.

These capabilities, unique to spectral cameras, are included with their general ability to discern object shape and size for detection and classification, as well as ranging distant or nearby objects when in a binocular configuration. Depending on the types of bands captured by the spectral camera, there may be advantages to using spectral cameras to negate the obstruction caused by falling snow or rain. Table 9 covers several spectral imaging cameras, their specifications, and relative cost:

Table 9. Spectral Camera Device Performance Parameters

Product Type	Resolution	Points of Spectral Resolution	Frames per Second	Unit Cost
Hyperspectral Camera	2.2 MP	100	170	$
Hyperspectral Camera	648 × 488	40–52	1	$$
Scanning Hyperspectral Camera	800 × 250	240	60	$$
Multispectral Camera	640 × 512	8	800	$$$

2.3.5 Light Detection and Ranging (LIDAR)

LIDAR systems provide one of the most accurate means of ranging the environment around a locomotive. A LIDAR system emits a laser beam downrange and measures the return signal to determine the LIDAR's distance from a specific object. This is done at a very high rate to piece together a three-dimensional collage of distance values representing the surrounding environment, referred to as a "point cloud." This three-dimensional point cloud image not only contains information about distance to objects but can also be used to discern object shape and size.

The rate at which the laser is fired is the scan rate, often measured in kilohertz (kHz). Higher scan rates provide higher resolution range information about the environment around the LIDAR unit. High scan rate is desired for the SP, but higher scan rate LIDAR sensors are costlier. Currently available commercial systems can calculate a distance measure 640,000 times per second. Since LIDAR systems rely on a strong signal return from the laser source, any weather conditions that may scatter the returning signal will negatively affect the LIDAR sensor's operation (e.g., rain, snow, dust, and lens obstruction). LIDAR systems are also limited by their operating distance, often being only a few hundred meters, although research in LIDAR technology is an active field with frequent commercial advancements. Table 10 lists several COTS LIDAR systems, their specifications, and cost.

Table 10. LIDAR Performance Parameters

Product Type	Maximum Range	Acquisition Rate	Unit Cost
LIDAR Module	215 meters	FOV 20° 10 kHz FOV 48° 20 kHz FOV 100° 40 kHz	$$
LIDAR System	120 meters	FOV 190° 30 kHz	$$$
LIDAR System	200 meters	FOV 360° 640 kHz	$$$$

2.3.6 Radio Detection and Ranging (RADAR)

RADAR can be used for object ranging, tracking, and, to some extent, object identification. RADAR systems have an advantage in their maximum range capability, which can be on the order of many miles. COTS RADAR systems, available for relatively low cost can also convey information about an object's composition. Inferences regarding the object's physical composition can be made by analyzing the reflected electromagnetic energy from an object; that is, the object's unique electromagnetic reflectivity. Objects also respond differently to different frequencies of RADAR signals, with lower frequency signals penetrating deeper into objects proportional to the signal's wavelength. This can provide further advantage to the SP in classifying objects and detecting objects through obstructions such as foliage or densely falling snow, rain, or fog.

RADAR antenna design is important due to the limited space atop a locomotive. The size of a RADAR antenna is a function of the operating frequency of the RADAR (i.e., lower frequencies require larger antennae) and its mode of operation. Certain modes of operation require that a RADAR system has two antennas: one for transmitting and one for receiving. This type of RADAR, known as a bistatic system, requires more space to operate. Table 11 lists several COTS RADAR systems, their specifications and relative cost.

Table 11. RADAR Performance Parameters

Product Type	Range	Peak Transmission Power	Unit Cost
Broadband 18-in. RADAR	200 feet to- ~27 miles	165 mW	$$
RADAR System	~65 feet to ~55 miles	4 kW	$$$
RADAR System	24 feet to ~82 miles	120 W	$$$
RADAR System	Unknown to ~110 miles	25 kW	$$$$

RADAR systems have several considerations with respect to downrange radiation exposure. They can be dangerous to persons or livestock downrange because electromagnetic energy can penetrate tissue and cause heating due to energy absorption. The rate of absorption of electromagnetic radiation which RADAR produces depends on the frequency of the electromagnetic waves. In general, electromagnetic energy absorption in tissue occurs between 1 megahertz and 10 gigahertz, which is well within RADAR operating ranges. Ultimately, the electromagnetic power density, usually measured in watts per square meter (W/m^2), at the object downrange will determine its risk to radiation. Most modern RADAR systems do not transmit one continual electromagnetic wave, but rather transmit brief pulses on the order of microseconds. RADAR systems often transmit pulses less than 1 percent of the time they are operating (i.e., called the RADAR duty cycle), meaning their true average operating power is orders of magnitude lower than their average power output. RADAR systems with transmission powers on the order of hundreds of kW will often have an average power output of a few hundred watts.

2.3.7 Time-of-Flight (TOF) Cameras

TOF cameras are a rapidly progressing technology that provides a means of accurate ranging of objects within a field-of-view. Like LIDAR and RADAR, TOF cameras operate on the principle of time-of-flight; transmitting a signal into the environment and calculating the distance to objects based on how long the signal takes to return. Unlike LIDAR and RADAR, a TOF camera does not send a single localized pulse at a time and waits for the return, but rather it illuminates the entire field-of-view with a pulse of light, generally from an LED or laser, and calculates the range of the entire field-of-view simultaneously. Each individual pixel of the TOF camera sensor calculates the time of flight of the emitted pulse of light. This gives an accurate three-dimensional picture of the environment on every illumination cycle. Each pixel generally measures the returning light intensity, or a phase shift of the returning pulse of light. The generated three-dimensional image contains distance information at every point within the image. This is useful for object ranging, tracking, as well as discerning object size and shape for object detection and classification.

TOF cameras have several limitations. There is a limited range of ambient light intensity in which TOF cameras can operate. It is difficult for some TOF cameras to operate in bright outdoor environments due to saturation of the image sensors. This technical limitation will have to be considered when sourcing COTS systems. TOF cameras are also limited by the maximum distance they can accurately range objects. Generally, these systems operate from several centimeters to a few hundred meters. Systems with long range capabilities come at a greater cost. Table 12 lists several COT TOF camera systems, their specifications, and relative cost.

Table 12. Time-of-Flight Camera Device Parameters

Product Type	Resolution	Frames Per Second	Max Range	Unit Cost
CMOS TOF Camera	640 × 480	30	8.3 meters	$
TOF Camera	640 × 480	20	13 meters	$$
TOF Camera Sensor	6464 × 4852	17.9	Unknown	$$$

2.3.8 Ambient Temperature

Ambient temperature sensors that measure outside air temperature around the lead locomotive are necessary to meet the SP requirements. The need to monitor ambient air temperature stems from railroad operating rules and procedures. When outside temperatures are at or below freezing, train operators must condition the train brakes periodically. This ensures that ice and snow buildup on the brake shoes does not interfere with train braking performance.

Modern temperature sensors tend to be relatively low in cost and operate over a wide temperature range. Considerations for temperature sensors are essentially limited to their desired output. Sensors typically have an analog current or analog voltage output, but sensors with digital output protocols such as Long-Range Wide Area Network (LoRaWAN®) do exist. The difference in cost between output types is negligible, and the output type has no impact on temperature sensor performance. Table 13 lists several COTS temperature sensors, their specifications, and relative cost.

Table 13. Temperature Sensor Performance Parameters

Product Type	Temp Range	Output Type	Unit Cost
Temperature Sensor	-55°C ~ 150 °C	Analog Current	$
Temperature Sensor	-30°C ~ 70 °C	LoRaWAN	$
Temperature Sensor	-55°C ~ 150 °C	Analog Current	$
Temperature Sensor	-55°C ~ 150 °C	Analog Current	$
Temperature Sensor	-40°C ~ 125 °C	Analog Voltage	$

2.3.9 SP Market Research Summary

Considering the tradeoffs between sensor types covered above, it is important to note that one type of sensor technology alone is not adequate to meet the needs of the SP. It is recommended that a suite of sensors working in concert be used. Table 14 highlights the different sensor types and what sensor data each can provide. Cells marked with an **"X"** signify the sensor type listed in the column can provide the sensor data listed in the row. An array of sensors is also better equipped to handle the low visibility conditions associated with inclement weather. Fusion of data from multiple sensor types lessens the impact of weather on one particular sensor.

Table 14. Sensor Data per Sensor Type

Sensor Data Feature	TOF Camera	Visual Camera Monocular	Visual Camera Binocular	Thermal Camera Monocular	Thermal Camera Binocular	Infrared Camera Monocular	Infrared Camera Binocular	Spectral Camera Monocular	Spectral Camera Binocular	RADAR	LIDAR	Temperature Sensor
Infrared spectral Information				X	X	X	X	X	X			
Visual spectrum information		X	X					X	X			
Multi-spectrum information								X	X			
Thermal signature				X	X							
Object EM reflectivity										X		
Near object ranging	X		X		X		X		X	X	X	
Far object ranging			X		X		X		X	X		
Ambient temperature												X

2.4 ATO System Safety Assessment

The focus of safety for this project was on hazards addressed by SP and regulatory requirements that may apply to the SP. This effort included:

- Review of the SP concept
- Review of regulatory requirements that may apply to SP, specifically 49 CFR Parts 229 and 236
- Initiation of preliminary hazard list
- Initiation of effort to draft SP safety requirements derived from the preliminary hazard list

- Initiation of effort to draft SP implementation guidance derived from regulatory requirements

Due to this project, the following interim work products grew to include:

- A preliminary hazard list
- A draft SP safety requirements
- SP developer's guidance

The preliminary hazard list prepared under this effort will be incorporated into the overall ATO system safety effort being conducted under a separate FRA-funded project. The preliminary hazard list is a work in progress and will be included in the overall ATO preliminary hazard analysis.

Researchers will refine the draft SP safety requirements while the safety assessment progresses under a separate FRA-funded project. The SP functional and performance requirements document will contain the SP safety requirements. Final SP safety requirements will be incorporated into the final draft of the SP requirements.

The safety analysis identified the need for a developer's guide that provides information to potential SP system developers regarding the various safety assurance processes and tests that must be performed to meet the safety objectives of the industry. While the creation of this developer's guide was initiated during this project, it will be completed as part of a separately funded FRA project.

3. Conclusion and Recommendations

The team conducted the ATO safety and sensor development project in conjunction with the broader ATO definition effort beginning in early 2018. In this effort, the research team, with guidance from railroad industry subject matter experts, developed a set of ATO onboard SP functional and performance requirements. The development of these requirements is the first step in defining the SP to the level required to satisfy the functional, performance, and safety requirements as established by the industry.

Based on direction from the industry AG, all SPs deployed in North American freight service must have a high degree of commonality of operations. This means that the operators of a system should be able to expect very little functional or performance differences between systems they own, and systems owned by other carriers. This requirement of commonality of performance necessitates the need for further definition of the SP. Future decomposition of SP system level requirements will need to be conducted to identify those functions that must be common across all SPs while not infringing upon a SP developer's ability to innovate. This additional definition was beyond the scope of this project but is intended to be addressed in follow-on efforts.

Field testing of COTS sensor technologies must be undertaken to better evaluate the performance and capabilities of sensors and sensor systems in the railroad environment. Field testing will allow for the verification and/or revision of SP system functional and performance requirements based on real-world experience. Field testing must also explore the use of multiple types of sensors and the fusion of data from those sensors to enhance SP functionality beyond what can be done by a single sensor type.

In addition to field testing of sensors and devices, testing should be conducted to evaluate various methods of processing sensor data. This testing should evaluate COTS processing systems and/or algorithms available for the processing of sensor data to determine the presence of objects/obstruction within the data set. In addition, this analysis should evaluate parallel and/or virtualized processing of sensor data. These processing methods may not only enhance the overall accuracy of SP information output, but may also provide an innovative method of meeting the required safety performance goals as established by the ongoing ATO system safety assessment.

4. References

1. U.S. Government Publishing Office, Title 49 CFR § 229–Railroad Locomotive Safety Standards, Electronic Code of Federal Regulations, 2020.
2. U.S. Government Publishing, Title 49 CFR § 236–Rules, Standards, and Instructions Governing the Installations, Inspection, Maintenance, and Repair of Signal and Train Control Systems, Devices, and Appliances, Electronic Code of Federal Regulations, 2020.

Abbreviations and Acronyms

ACRONYM	DEFINITION
AG	Advisory Group
AOI	Area of Interest
AAR	Association of American Railroads
ATO Ex	Automated Train Operations Executive
ATO	Automated Train Operations
BNSF	Burlington Northern Santa Fe Railway
CN	Canadian National Railway
CP	Canadian Pacific Railway
CCD	Charge-Coupled Device
CFR	Code of Federal Regulations
COTS	Commercial Off-the-shelf
COI	Condition of Interest
CONOPs	Concept of Operations
CSX	CSX Corporation
EMS	Energy Management System
EO	Electro-Optical
FRA	Federal Railroad Administration
FOV	Field of View
FW	Firmware
fps	Frames-per-second
HW	Hardware
HMI	Human Machine Interface
IEEE	Institute of Electrical and Electronics Engineers
IRS	Interface Requirements Specifications
ITC	Interoperable Train Control
ITC-ATO	Interoperable Train Control-Automated Train Operations

ACRONYM	DEFINITION
ITC-ATOSS	Interoperable Train Control-Automated Train Operations Support Systems
ITC-EMS	Interoperable Train Control-Energy Management System
ITC-PTC	Interoperable Train Control-Positive Train Control
ITCSM	Interoperable Train Control System Management
InTC	Intra-train Conditions
KSC	Kansas City Southern Railway Company
kHz	Kilohertz
LIDAR	Light Detection and Ranging
LoRaWAN	Long Range Wide Area Network
MSRP	Manual of Standards and Recommended Practices
MP	Megapixel
MIL-STD	Military Standard
NTP	Network Time Protocol
NS	Norfolk Southern Railway
OOI	Object of Interest
OB	Onboard
PCS	Pneumatic Control Switch
PTC	Positive Train Control
POST	Power on Hardware Self-tests
RADAR	Radio Detection and Ranging
RGB	Red, Green, Blue
ROW	Right-of-Way
SP	Sensor Platform
SoS	System of Systems
TWG	Technical Working Group
TOF	Time-of-Flight
TBC	To Be Configured

ACRONYM	DEFINITION
TBD	To Be Determined
TCCO	Train Control, Communications and Operations Committee
TTCI	Transportation Technology Center, Inc.
UP	Union Pacific Railroad

Appendix A.
SP Requirements Document

Locomotive Onboard Sensor Platform
System Requirements

Initial Release

Revision 1.0

Prepared by

Transportation Technology Center, Inc.

September 25, 2020

REVISION RECORD

Revision	Date	Description
1.0	September 25, 2020	Initial Release

1. Introduction

This document defines functional requirements for a locomotive onboard sensor platform (SP) system to support Automated Train Operations (ATO). The SP monitors the environment ahead of and around the lead locomotive of the train. Regions which the SP monitors include foul volume, track and road structures including bridges and tunnels, and right-of-way. The SP monitors these regions for conditions that present hazards, such as obstructions; as well as the state of specific objects such as the activation state of crossing protection systems and alignment of switches.

1.1 Purpose of ATO SP Subsystem Requirements Document

The primary purpose of this document is to define requirements for a SP suitable for use in the North American railroad environment with sufficient detail to allow for the interoperable operation of multiple SP system deployments regardless of manufacturer, developer, or integrator of the SP system as a whole. For the purposes of this document, interoperability means that an ATO-equipped locomotive can be operated by any railroad with the necessary infrastructure, on any railroad's territory, and supported by any railroad's qualified personnel, while allowing the flexibility for each railroad to design, procure, implement and package these requirements per their own business needs.

1.2 ATO SP System Requirements Document Scope

This document defines the interoperable functional and performance requirements for a locomotive onboard SP system that satisfies the needs of a high automation level ATO system.

Each section of this document generally contains two parts: narrative text and explicit requirements. The narrative text includes background information, goals and other supplemental information provided to clarify the requirements. In accordance with RFC 2119, the following terms are used to identify requirements, preferences or recommendations, and options:

- Absolute requirements contain the word "shall" and follow in a lettered list beneath the narrative text
- Absolute prohibitions contain the term "shall not" and follow in a lettered list beneath the narrative text along with absolute requirements
- Recommendations identified as such and use the word "should" or "recommended" rather than "shall." The use of should means that there may exist valid reasons in particular circumstances to ignore a particular item, but the full implications must be understood and carefully weighed before choosing a different course.
- Recommendations against an undesirable system feature or behavior is identified with "should not" or "not recommended." The use of these terms mean that there may exist valid reasons in particular circumstances when the particular behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.

- The term “may” or “optional” indicate system features or behaviors that are truly optional.

1.3 ATO SP System Objectives

The ATO SP defined in this document is to be developed to meet the safety, business, and interoperability requirements of the Association of American Railroads (AAR) and AAR member railroads. The requirements in the following sections are necessary for ATO system interoperability; other factors, like business specific functionality, are outside the scope of this document.

2. Applicable Documents

The following documents apply to the ATO SP:

1. *AAR Manual of Standards and Recommended Practices (MSRP), Section K-I, "Railway Electronics Systems Architecture and Concepts of Operation"*
   - Standard S-9010.V1.0, "Data Protection"
2. *MSRP Section K-II, "Locomotive Electronics and Train Consist System Architecture"*
   - Standard S-9101.V1.0, "Locomotive Electronics System Architecture"
   - Standard S-9102, "Locomotive System Time Synchronization" (In Development)
3. *MSRP Section K-IV, "Office Architecture and Railroad Electronics Messaging"*
   - Standard S-9356.V2.0, "Class D Messaging"
4. *MSRP Section K-V, "Electronics Environmental Requirements and System Management"*
   - Standard S-9401.V1.0, "Railroad Electronics Environmental Requirements"
   - Standard S-9451.V1.1, "ITCSM Common Systems Management Requirements"
5. *AAR MSRP, Section M, Locomotive Electronics Safety Assessments and Analyses, Specification M-1005*
6. *AAR MSRP, Section M, Plate L—Locomotive Diagram for Interchange Service, Standard S-5510*
7. Title 49 CFR Part 229–Railroad Locomotive Safety Standards
8. MIL-STD-882E–System Safety
9. Automated Train Operations Executive (ATO Ex) to Sensor Platform Interface Requirements Specification (i.e., IRS-ATO Ex to ATO SP)

3. ATO SP System Overview

The SP is a locomotive-borne system consisting of a set of sensors that provide data regarding the external operating environment ahead of the train, and an analysis engine that processes the sensor data and provides actionable information to locomotive onboard systems. External conditions include conditions within the environment ahead of and around the lead locomotive of the train. SP monitors zones which includes the foul volume, track and road structures including bridges and tunnels, and right of way. Zones monitored by the SP are depicted in Figure A1. SP monitors these zones to initiate the appropriate train response for conditions that present hazards, such as track obstructions and people encroaching within the foul volume (i.e., Objects of Interest [OOI]); as well as the state of specific objects such as the activation state of crossing protection systems and alignment of switches (i.e., Condition of Interest [COI]).

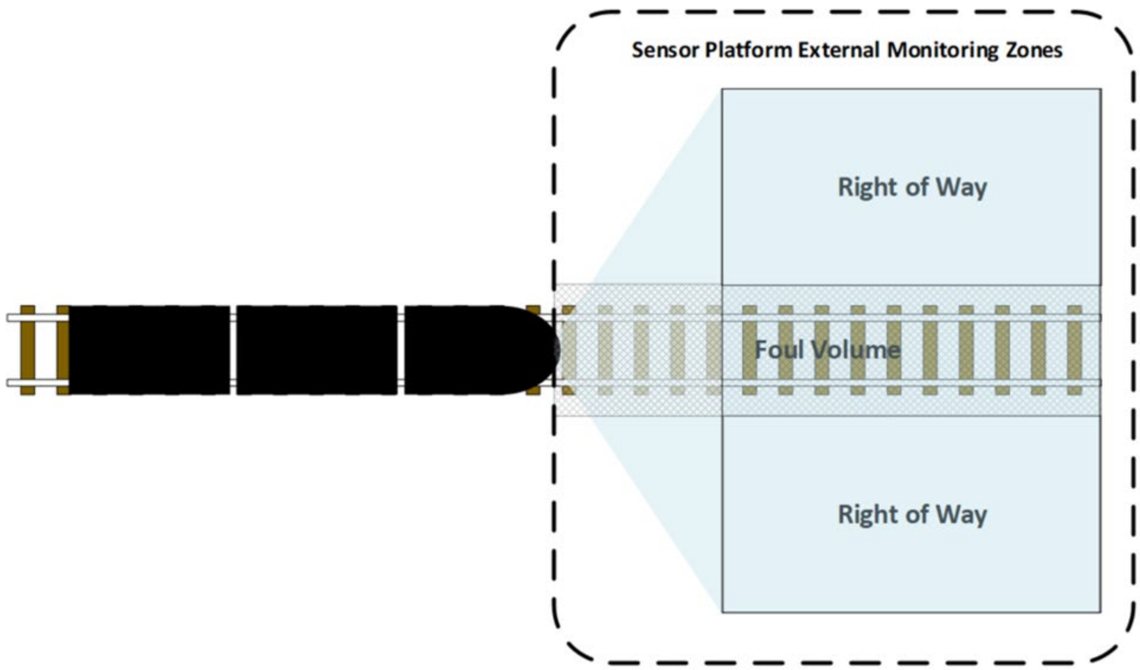

Figure A1. SP External Monitoring Zones

The sensor data is processed by the SP to do the following:

- Detect potential hazards, referred to as OOIs and COIs
- Classify OOIs and COIs to discriminate objects that present a hazard from those that do not
- Localize OOIs and COIs relative to the leading edge of the train and intended route of the train
- Track OOIs and COIs outside of the foul volume to determine if they may enter the foul volume
- Calculate probability of intercept

Upon completion of sensor data analysis, sensor platform provides actionable information to ATO Ex which is used in determining necessary train response. The functional SP architecture is provided in Figure A2. This document serves to define the function and performance of the SP as a system.

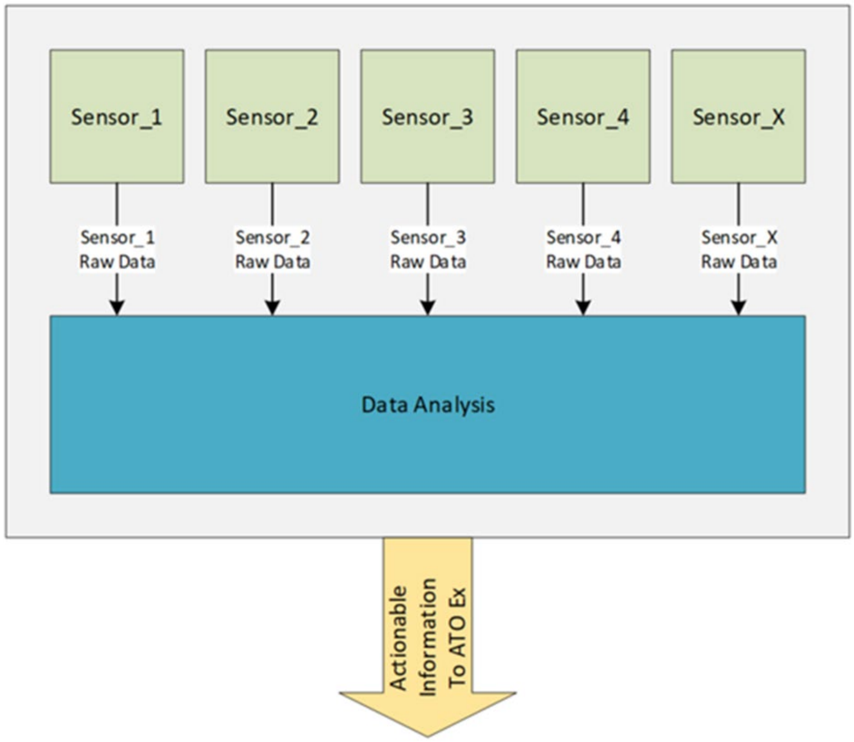

Figure A2. ATO SP High Level Architecture

4. ATO SP Systems Functional Requirements

4.1 SP System States

The SP operates within a limited number of possible states. Each operating state of the SP has defined entrance criteria, exit criteria, and functionality. Table A1 lists and defines the SP states. Figure A3 illustrates a visual representation of the SP states. Table A2 defines transition criteria between states.

Table A1. SP State Definitions

ATO SP State	*ATO SP State Description*
Power-On	Initial state of the SP when power is applied to the system or when the SP performs a system reboot. While in the power-on state, the SP: 1. Performs diagnostic tests on platform hardware, operating system(s), and system software 2. Initiates operation of system software 3. Verify presence and health of connected sensor devices 4. Records results of SP power-on diagnostic tests
Initialization	A state in which the SP: • Establishes communications with ATO Ex • Synchronizes internal SP time to onboard NTP server • Negotiates with ATO Ex the selection of a mutually supported IRS version • Validates that the current SP configuration is valid
Standby	A state in which SP synchronizes operational data with ATO Ex.
Active	A state in which the SP is actively monitoring the external environment ahead of the train and providing actionable information to ATO Ex.
Maintenance	A state that facilitates any life-cycle maintenance activities to include fault log analysis, software and/or firmware upgrades, and potential periodic sensor and/or system calibration.
Failed	A state in which a hardware or software error has been detected.

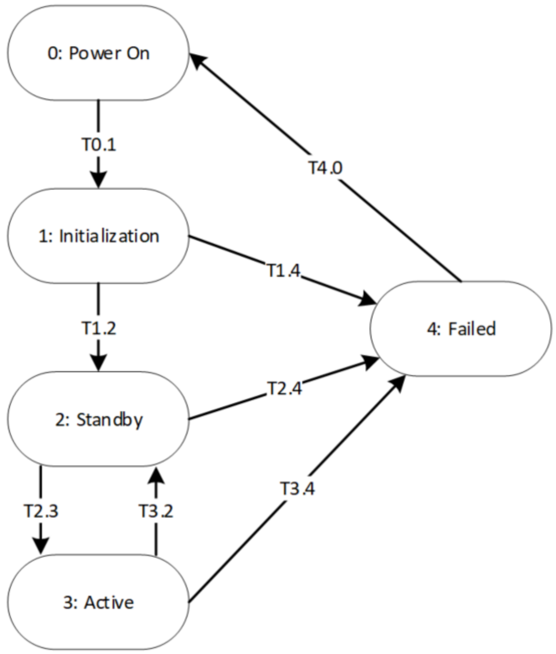

Figure A3. SP System States Diagram

Table A2. SP State Transition Criteria

State Transition	Transition Criteria
T0.1 (Power-on to Initialization)	Successful completion power on process
T1.4 (Initialization to Failed)	Software or hardware failure detected
T1.2 (Initialization to Standby)	**AND** • Established comms with ATO Ex • IRS version negotiated with ATO Ex • Date/time sync'd to NTP server per S-9102 • Confirmed valid SP configuration
T2.4 (Standby to Failed)	Software or hardware failure detected
T2.3 (Standby to Active)	**AND** • ATO Ex transitions to Unarmed Configured state via ATO Ex to ATO SP Status message • Operational data sync'd with ATO Ex (e.g., track data, train route, etc.)
T3.5 (Active to Failed)	Software or hardware failure detected

State Transition	Transition Criteria
T3.2 (Active to Standby)	When commanded
T4.0 (Failed to Power-On)	Power supply breaker cycled

4.1.1 SP Power-On State

The SP power-on state is intended to perform several integrity tests before further system initialization takes place. Within the power-on state, SP performs the power on self-test process to verify integrity of hardware, firmware, and operating system. The power-on state functions are performed sequentially. The power-on state function diagram is shown below in Figure A4.

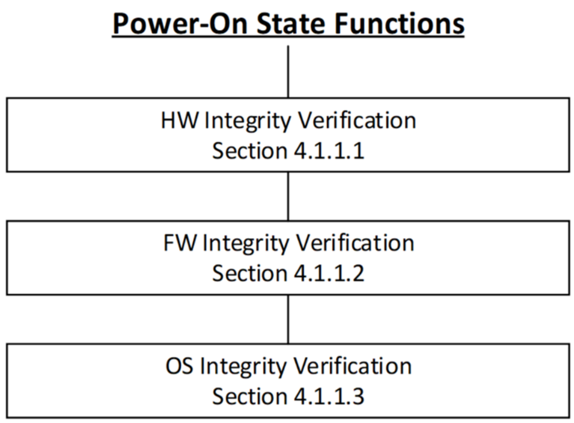

Figure A4. Power-On State Function Diagram

In the event the SP fails to pass any test performed during a power-on function, the SP stops the power-on processes and records results of the boot-up process to the boot log. Visual indication of a system failure in the power-on state is also displayed.

4.1.1.1 Hardware Integrity Verification

When power is applied, or the SP undergoes a hard reset (i.e., power is removed from SP and reapplied), SP conducts HW self-test(s) to verify HW integrity.

a) *Upon application of power, the SP shall conduct power on hardware self-tests (POST) to verify HW integrity.*

b) *The SP shall display a visual indication that HW integrity self-test(s) are in progress.*

c) *If the SP fails a HW integrity self-test(s), the SP shall display a visual indication of HW integrity self-test(s) failure.*

d) *If the SP fails a HW integrity self-test, the SP shall abort the boot-up process.*

e) *Results of successful HW integrity self-test(s) shall be recorded in a boot log.*

f) *Results of failed HW integrity self-test(s) shall be recorded in a boot log.*

4.1.1.2 Firmware Integrity Verification

Upon successful completion of HW integrity tests, the SP conducts FW self-test(s) to verify integrity of system FW.

a) *Upon successful completion of hardware integrity verification, the SP shall conduct self-test(s) to verify FW integrity.*

b) *The SP shall display a visual indicator displaying that FW integrity self-test(s) are in progress.*

c) *If the SP fails a FW integrity self-test(s), the SP shall display a visual indicator of FW integrity self-test(s) failure.*

d) *If the SP fails a FW integrity self-test, the SP shall abort the boot-up process.*

e) *Results of successful FW integrity self-test(s) shall be recorded in a boot log.*

f) *Results of failed FW integrity self-test(s) shall be recorded in a boot log.*

4.1.1.3 Operating System Integrity Verification

Upon successful completion of FW integrity tests, the SP initiates the operating system and conducts self-test(s) to verify OS integrity.

a) *The SP shall initialize the OS upon successful completion of the FW integrity verification.*

b) *The SP shall conduct self-test(s) to determine OS integrity.*

c) *If the SP fails an OS integrity self-test, the SP shall abort the boot-up process.*

d) *If the SP fails an OS integrity self-test, the SP shall display a visual indicator of OS integrity self-test failure.*

g) *Results of failed OS integrity self-test(s) shall be recorded in a boot log.*

4.1.1.4 Transition Criteria from Power-On State to Initialization State

Upon successful completion of the SP HW, SW, OS, and application SW integrity self-tests, the SP transitions from the power-on state to the Initialization state.

a) *Upon successful completion of the SP integrity self-tests, the SP shall transition from the power-on state to the Initialization state.*

4.1.2 Initialization State

The SP Initialization state serves to configure the SP system before transition to the standby state. The SP enters the Initialization state after successful completion; SP power-on state functions. The SP Initialization State Functions includes:

- Synchronization of the SP clock with the locomotive onboard network time service via network time protocol (NTP)
- Initiation of the SP ITC System Management (ITCSM) client
- Initialization of the SP application software

Initialization of the SP application software includes verification of SP application software integrity, followed by:

- Negotiation of interface version with ATO Ex
- Verification of SP configuration with ATO Ex after interface negotiation
- SP verification of sensor devices

Figure A5 provides an overview of the SP Initialization state functions.

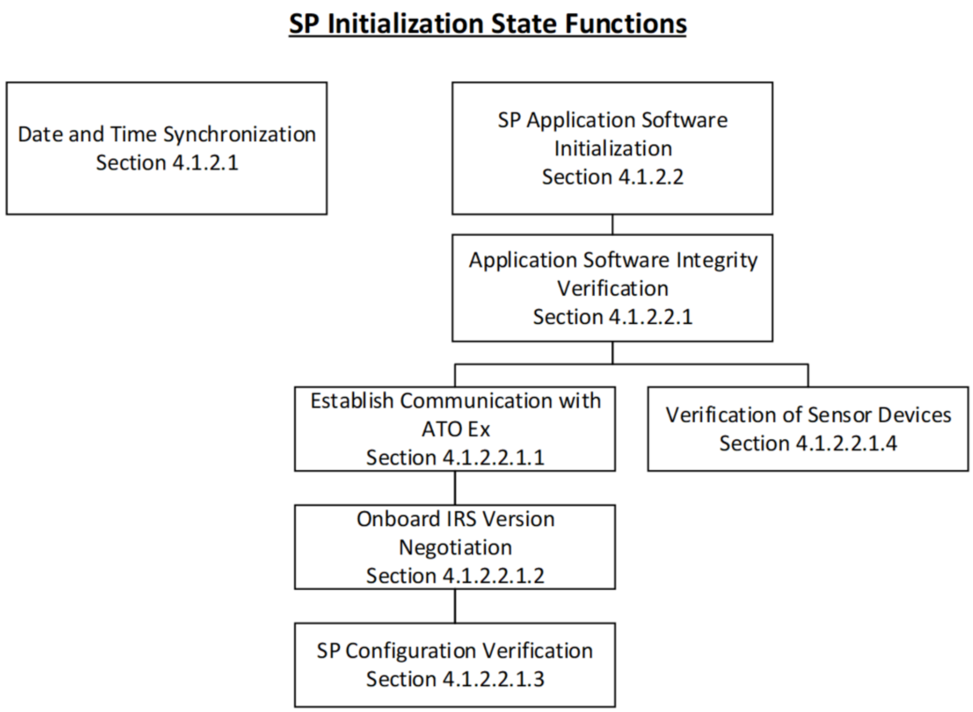

Figure A5. SP Initialization State Function Diagram

4.1.2.1 Date and Time Synchronization

Upon entering the Initialization state, the SP synchronizes the date and time to an AAR MSRP S-9102 compliant locomotive onboard NTP server via the locomotive network interface. While in the Initialization state, the SP will abort the initialization process and transition to the Failed state if the SP internal system clock fails to synchronize after SP_TBD001 seconds.

a) *Upon entering the Initialization state, the SP shall synchronize internal system clock with the AAR MSRP S-9102 compliant locomotive onboard NTP server.*

b) *The SP shall communicate with the locomotive onboard NTP server via the locomotive network interface.*

c) *If the SP fails to synchronize the SP internal system clock after SP_TBD001 seconds, the SP shall transition to the Failed state.*

d) *The SP shall record failures to synchronize the SP internal system clock in the event log.*

e) *The SP shall record successful synchronization of the SP internal system clock in the event log.*

4.1.2.2 SP Application Software Initialization

The SP initializes application software upon entering the Initialization state.

a) *Upon entering the Initialization state, the SP shall initialize application software.*

4.1.2.2.1 Application Software Integrity Verification

SP software integrity self-tests serve to verify the application executables have not been corrupted or undergone unauthorized changes. SP software integrity tests are performed prior to operation of SP functions. If the SP application software integrity tests fail, the SP shall terminate execution of the SP application software.

a) *Upon successful completion of the SP application software initialization, the SP shall verify the application SW integrity.*

b) *If the SP fails an application SW integrity self-test, the SP shall abort the execution of the SP application SW.*

c) *If the SP fails an application software integrity self-test, the SP shall display a visual indicator of system initialization failure.*

d) *The SP shall record the failure of an application software integrity self-test in the event log.*

e) *The SP shall record successful application software integrity self-tests in the event log.*

4.1.2.2.1.1 Establish Communications with ATO Ex

After successful completion of the SP application software integrity verification, the SP establishes communication with ATO Ex. Requirements that define the parameters necessary to establish a Class D connection with ATO Ex are defined within the ATO Ex to ATO SP IRS.

a) *Upon successful completion of the application software integrity verification, the SP shall establish a Class D connection with ATO Ex as defined in the ATO EX – ATO SP IRS.*

4.1.2.2.1.2 Onboard IRS Version Negotiation

When the SP receives the initial valid status message from ATO Ex, the SP negotiates the IRS version that will be used between the two subsystems. The SP uses the ATO Ex to ATO SP Status (Q600) message to identify and select a mutually supported IRS version to use for communications. Prior to the SP interface negotiation with ATO Ex, the SP uses the SP preferred IRS version for communication with ATO Ex.

a) *Prior to the IRS version negotiation with ATO Ex, the SP shall use the ATO Ex – ATO SP preferred IRS version for communication with ATO Ex.*

4.1.2.2.1.2.1 Supporting Multiple Interface Versions

The SP supports communication with ATO Ex in a manner that satisfies the requirements within either the preferred IRS version or acceptable IRS version. The SP selects which IRS version will be used to communicate with ATO Ex during the interface version negotiation process. The preferred and acceptable IRS versions are identified by the owning railroad. The owning railroad may only identify a single IRS version as preferred/acceptable. The preferred IRS version is the most recent allowed (i.e., version N) IRS version released. The acceptable IRS version is typically the N-1 IRS version allowed. The SP supports communication with ATO Ex in a manner that satisfies the requirements within a single preferred/acceptable IRS version as defined by the owning railroad.

a) *The SP shall support communication in a manner that satisfies the requirements defined in the owning railroad preferred ATO Ex – ATO SP IRS version.*

4.1.2.2.1.2.1.1 Interface Version Negotiation with ATO Ex

After the SP receives a valid ATO Ex to ATO SP Status (Q600) message, being triggered by the initial ATO SP to ATO Ex Status (Q700) message, the SP selects the most recent mutually supported IRS version based on the preferred and acceptable fields in the ATO Ex to ATO SP Status (Q600) message as outlined in Figure A6.

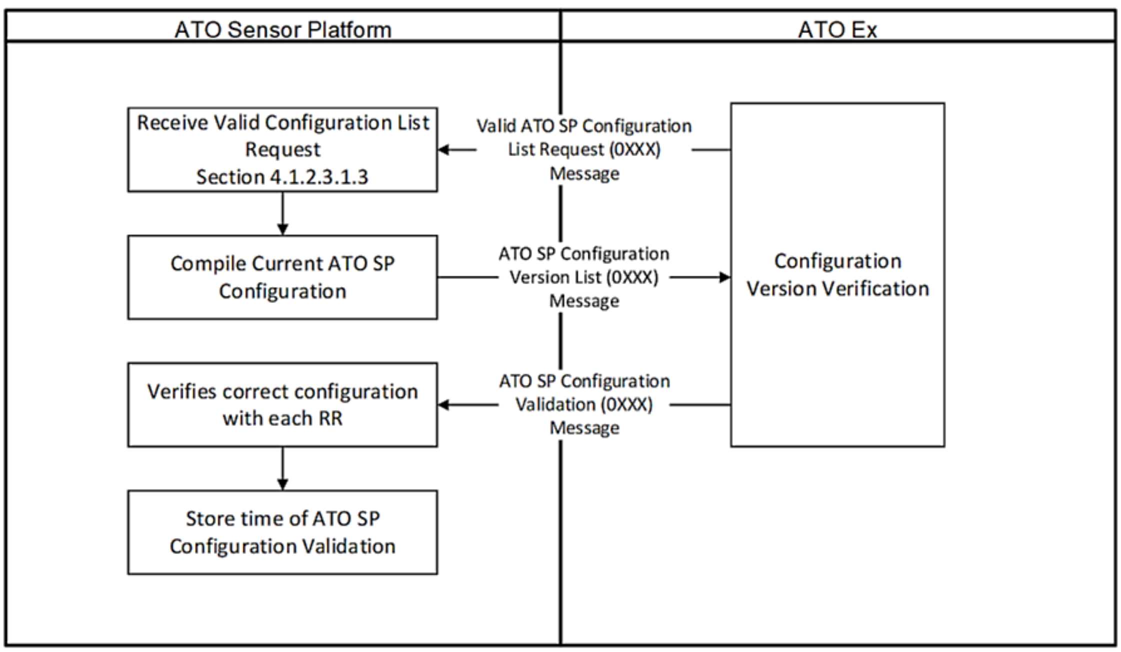

Figure A6. Interface Version Negotiation Process Diagram

a) *Upon initiating the version negotiation process, the SP shall send the ATO SP to ATO Ex Status (Q700) message to ATO Ex with the following information:*

   1) *Active IRS Version*

   2) *Preferred IRS Version*

   3) *Acceptable IRS Version*

4) *ATO SP State*

5) *Session ID*

b) *Upon initiating the version negotiation process, SP shall send the ATO SP to ATO Ex Status (Q700) message to ATO Ex with unused fields set to unused values per the ATO Ex – ATO SP IRS.*

c) *If the Active IRS version field in the valid ATO Ex to ATO SP Status (Q600) message matches the currently active ATO SP IRS version for ATO Ex, ATO SP shall continue to use the currently active IRS version for communication with ATO Ex.*

d) *If the Active IRS version field in the valid ATO Ex to ATO SP Status (Q600) message does not match the current active ATO SP IRS version for ATO Ex, the SP shall select the Preferred ATO Ex – ATO SP IRS version for use if the preferred ATO Ex IRS field = Preferred ATO SP IRS version.*

e) *If the Active IRS version field in the valid ATO Ex to ATO SP Status (Q600) message does not match the current active ATO SP IRS version for ATO Ex, the SP shall select the Preferred ATO Ex – ATO SP IRS version for use if the acceptable ATO Ex IRS field = Preferred ATO SP IRS version.*

f) *Upon successful negotiation of a mutually supported interface, the SP shall send the ATO SP to ATO Ex Status (Q700) to ATO Ex with the following fields active:*

1) *Active IRS Version field*

2) *Preferred IRS Version field*

3) *Acceptable IRS Version field*

4) *ATO SP State*

5) *Session ID*

4.1.2.2.1.2.1.2 Failure to Identify Mutually Supported Interface with ATO Ex

If the SP fails to identify a mutually supported ATO Ex to ATO SP interface version after receiving a valid ATO Ex to ATO SP Status (Q600) message, the SP transitions to the failed state.

a) *Upon failure to identify a mutually supported interface with ATO Ex, the SP shall transition to the Failed state.*

b) *The SP shall record the failure to identify mutually supported interface with ATO Ex in the event log.*

4.1.2.2.1.3 SP Configuration Verification

The SP performs configuration verification in the Initialization state. This process verifies the SP configuration associated with each operating railroad on the train's intended route. Figure A7 illustrates the SP configuration verification process.

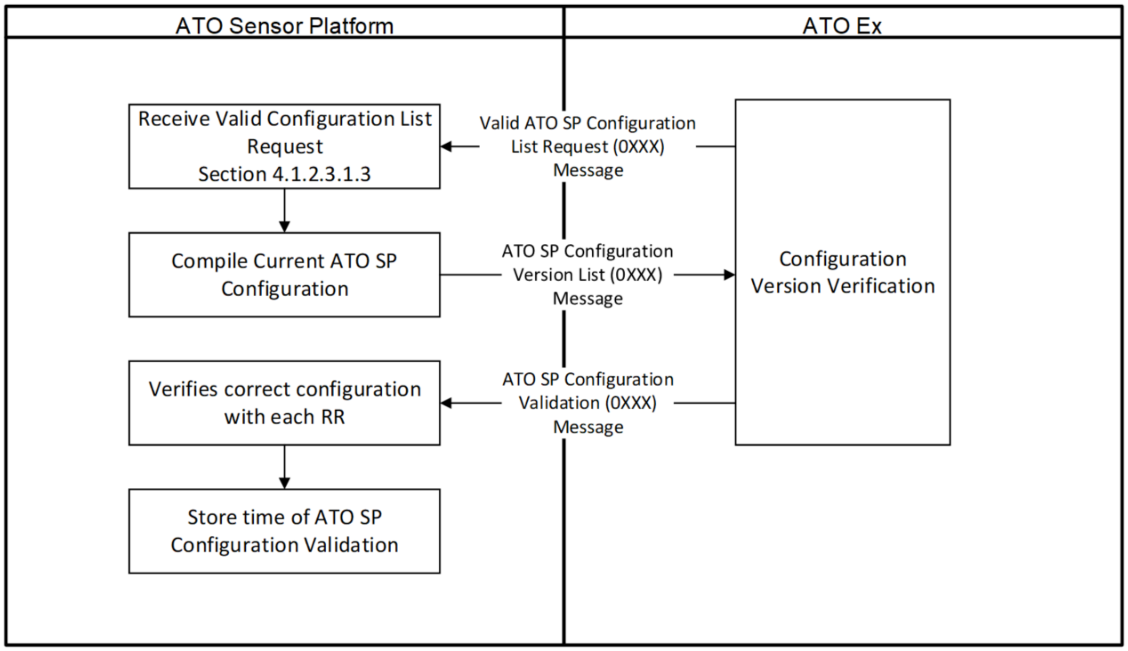

Figure A7. SP Configuration Verification Process Diagram

4.1.2.2.1.3.1 SP Configuration Version List (Q735) Message

ATO Ex requests the configuration verification list information by sending the ATO SP Configuration Version List Request (Q630) message to the SP. Upon receipt of the ATO SP Configuration Version List Request (Q630) message from ATO Ex, the SP compiles the current SP configuration and sends the ATO SP Configuration Version List (Q735) message.

a) *Upon receiving a valid ATO SP Configuration List Request (Q630) message from ATO Ex, the SP shall compile the current SP configuration.*

b) *Upon compiling the current SP configuration, the SP shall send the ATO SP Configuration Version List (Q735) message as defined in the ATO SP to ATO Ex IRS to ATO Ex.*

4.1.2.2.1.3.2 ATO Ex to ATO SP Configuration Validation (Q640) Message

The SP verifies whether the SP configuration is valid based on the ATO Ex to ATO SP Configuration Validation (Q640) message. Upon receipt of an ATO Ex to ATO SP Configuration Validation (Q640) message, the SP verifies the configuration as either valid or invalid. Verifying that the configuration is valid, ATO SP may transition to the Standby state. If the configuration is found to be invalid, the SP transitions to the Failed state.

Note: Messages are defined in the ATO SP to ATO Ex IRS.

a) *The SP shall verify the current SP configuration is valid with each operating railroad upon receipt of a valid ATO Ex to ATO SP Configuration Validation (Q640) message.*

b) *If the current SP configuration is valid based on the ATO Ex to ATO SP Configuration Validation (Q640) message, the SP shall store the time of validation in the event log.*

c) *If the current SP configuration is invalid based on the ATO Ex to ATO SP Configuration Validation (Q640) message, the SP shall transition to the Failed state.*

4.1.2.2.1.4 Verification of Sensor Devices

Verification of sensor devices begins in the SP Initialization state, after date and time has been synchronized with the onboard NTP server. The SP verifies the presence of each sensor by comparing an internally stored record of all sensor devices comprising the SP. The SP also performs diagnostic tests on each sensor to ensure proper functionality. The SP records the presence of each sensor and the results of the verification. If a sensor is found to be malfunctioned, the SP will enter the Failed state and create an exception condition which is reported to ATO Ex.

a) *The SP shall have an internally stored record of each sensor device comprising the SP.*

b) *The SP shall verify the presence of each sensor device in the Initialization state.*

c) *The SP shall record the sensor devices present in the event log.*

d) *The SP shall perform a diagnostics verification on each sensor device.*

e) *The SP shall record the results of the diagnostics verification tests in the event log.*

f) *If the SP detects a sensor device malfunction, the SP shall transition to the Failed state.*

4.1.2.3 Initialization State to Standby State Transition Criteria

Several criteria must be satisfied before the SP can transition from an Initialization state to Standby state. The SP transitions from the SP Initialization state to the Standby state after all the following have been satisfied:

- Date and Time Synchronization
- SP Configuration Verification
- Verification of Sensor Devices

If one or more of the listed criteria is not satisfied, the SP will not transition to the Standby state.

a) *The SP shall transition from the SP Initialization state to the Standby state after:*

   I. *Date and time are synchronized with locomotive onboard NTP service*

   II. *SP verified the "Configuration Verification" field = "Valid" in the ATO Ex to ATO SP Configuration Verification (Q640) message.*

   III. *Verification of Sensor Devices*

4.1.2.4 Initialization State to Failed State Transition Criteria

The SP transitions to a Failed state when a hardware or a software failure in the initialization process occurs. Additional failures resulting in a transition to the Failed state include:

- Failure to synchronize date and time with onboard locomotive NTP server
- Failure to identify mutually supported interface version with ATO Ex

- Failure to verify SP configuration
- Failure(s) in sensor device verification

Failed state transition requirements can be found in the respective functional sections above.

4.1.3 Standby State

Upon successful completion of SP Initialization, the SP enters SP Standby state. While in the Standby state, the SP performs system health self-checks, exchanges status messages with the ATO Ex (polling process), and synchronizes track data with the ATO Ex.

The SP Standby state allows the SP to be configured for transition to active state upon verification from ATO Ex that ATO Ex is in the Unarmed Configured state. The SP Standby state allows for a transition out of the Active state without going through the Initialization state process. Once in the Standby state the SP performs functions in the sequence defined in Figure A8.

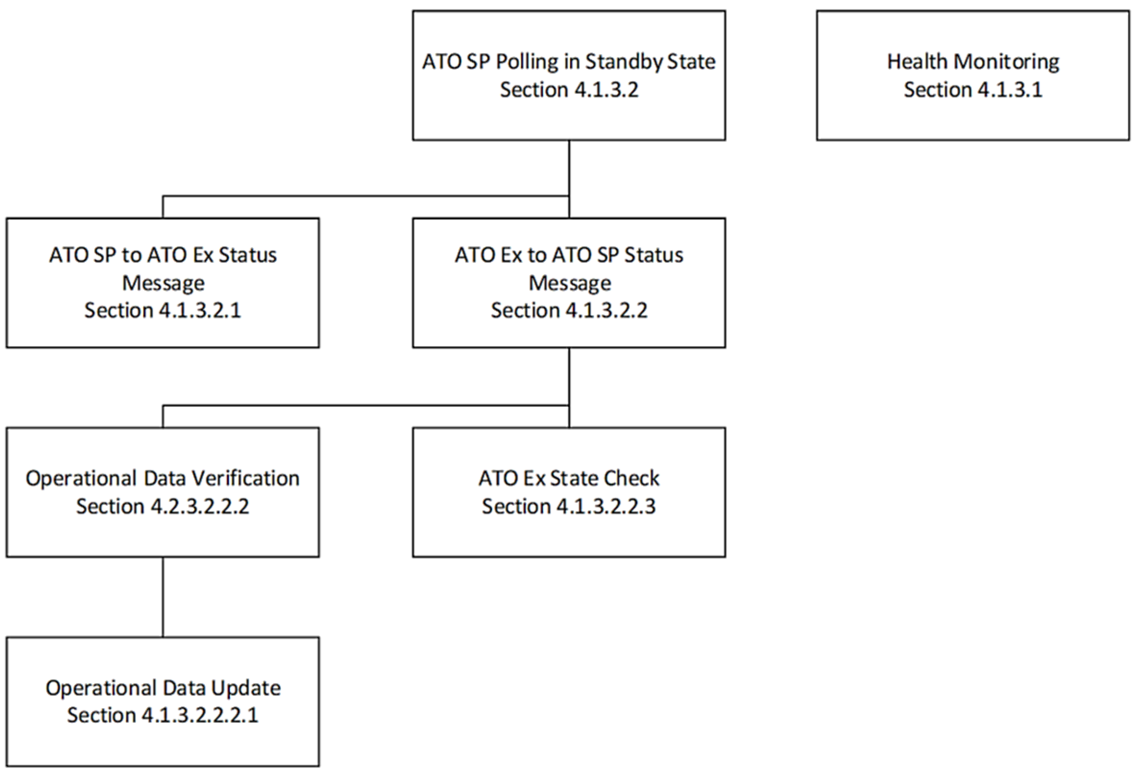

Figure A8. Standby State Function Diagram

4.1.3.1 Health Monitoring

The SP monitors the integrity of the hardware and software from the time the SP enters the Standby state. Any detected failure will cause a transition to the Failed state.

a) *The SP shall conduct system HW integrity monitoring at an interval of no less than SP_TBD002 (60) seconds while in the Standby state.*

b) *The SP shall transition to the Failed state when a HW integrity failure is detected.*

c) *The SP shall conduct system SW integrity monitoring at an interval of no less than SP_TBD002 (60) seconds while in the Standby state.*

d) *The SP shall transition to the Failed state when a SW integrity failure is detected.*

4.1.3.2 ATO SP Polling in the Standby State

The SP initiates polling with ATO Ex upon entering the Standby state. Polling between the ATO SP and ATO Ex facilitates the exchange of the status message (i.e., heartbeat). The process for polling in the Standby state is shown in Figure A9 below.

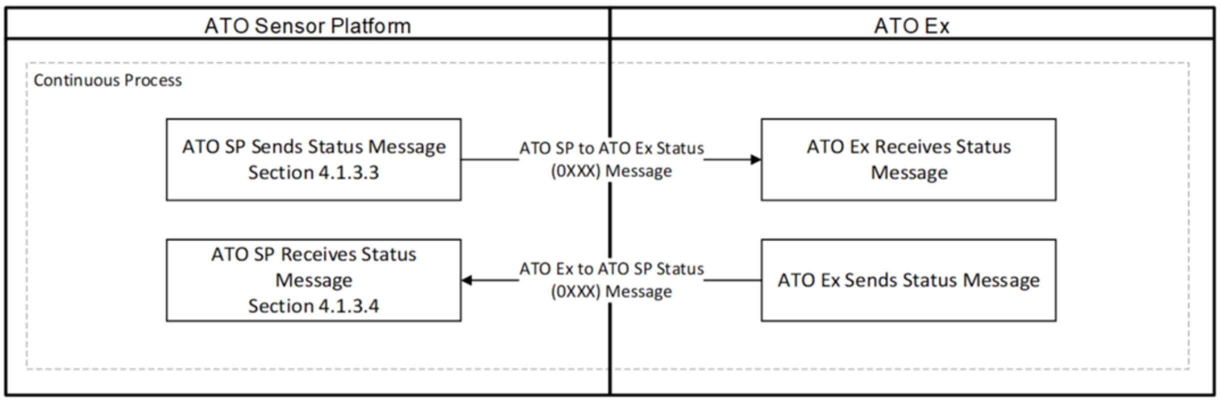

Figure A9. ATO SP Polling Activity in the Standby State

4.1.3.2.1 ATO SP to ATO Ex Status (Q700) Message in the Standby State

When the SP is in the Standby state, the SP sends the ATO SP to ATO Ex Status (Q700) message every SP_TBD003 (1) seconds.

Note: IRS requirements that define the values the SP populates in each status (Q700) message field will change dependent on the system state. The ATO Ex – ATO SP IRS contains requirements defining the values the SP populates in each ATO SP to ATO Ex Status (Q700) message field in the SP Standby state.

a) *The SP shall send the ATO SP to ATO Ex Status (Q700) message to the ATO Ex every SP_TBD003 (1) seconds while in the Standby state.*

b) *Upon entering the Standby state, the SP shall send the ATO SP to ATO Ex Status (Q700) message to ATO Ex with the following information:*

   1) *Active IRS Version*

   2) *Preferred IRS Version*

   3) *Acceptable IRS Version*

   4) *ATO SP State*

5) *ATO SP Status Flags*

6) *Session ID*

c) *Upon entering the Standby state, the SP shall send the ATO SP to ATO Ex Status (Q700) message to ATO Ex with unused fields set to unused values per the ATO Ex – ATO SP IRS.*

4.1.3.2.2 ATO Ex to ATO SP Status (Q600) Message in the Standby State

The SP receives the ATO Ex to ATO SP Status (Q600) message in the SP Standby state to maintain a heartbeat with the ATO Ex. Upon receipt of the ATO Ex to ATO SP Status (Q600) message from the ATO Ex, the SP verifies the integrity of ATO Ex to ATO SP Status (Q600) message as defined in the ATO Ex – ATO SP IRS. The SP requirements related to verifying the integrity of the message in the ATO Ex – ATO SP IRS includes, but is not limited to, acceptable range of values, message completeness, and acceptable receive time. ATO Ex – ATO SP IRS defines what fields in the ATO Ex to ATO SP Status (Q600) message are ignored while in the SP Standby state.

a) *The SP shall accept valid ATO Ex to ATO SP Status (Q600) messages from the ATO Ex while in the Standby state.*

b) *The SP shall reject invalid ATO Ex to ATO SP Status (Q600) messages while in the Standby state.*

4.1.3.2.2.1 Failure to Receive Valid ATO Ex to ATO SP Status (Q600) Message in the ATO SP Standby State

When the SP fails to receive a valid ATO Ex to ATO SP Status (Q600) message for SP_TBD004 (5) seconds after the previously received valid ATO Ex to ATO SP Status (Q600) message, the SP transitions to the SP Failed state.

a) *The SP shall transition to Failed state if the SP fails to receive a valid ATO Ex to ATO SP Status (Q600) message for SP_TBD004 (5) seconds after the previously received valid ATO Ex to ATO SP Status (Q600) message while in the Standby state.*

4.1.3.2.2.1.1 Internal Record of Failure to Receive Valid ATO Ex to ATO SP Status (Q600) Message in ATO Ex Standby State

To support local diagnostics, the SP internally records the failure to receive a valid ATO Ex to ATO SP Status (Q600) message for SP_TBD004 (5) seconds after the previously received valid ATO Ex to ATO SP Status (Q600) message in the SP Standby state, or when the SP rejects an ATO Ex to ATO SP Status (Q600) message while in the SP Standby state.

a) *If the SP fails to receive a valid ATO Ex to ATO SP Status (Q600) message for SP_TBD004 (5) seconds after the previously received valid ATO Ex to ATO SP Status (Q600) message while in the SP* Standby *state, the SP shall internally record the failure to receive a valid ATO Ex to ATO SP Status (Q600) message in the event log.*

b) *The SP shall internally store the failure to receive a valid ATO Ex to ATO SP Status (Q600) message while in the Standby state in the event log for SP_TBD005 (184) days.*

c) *The SP shall internally store the rejection of an ATO Ex to ATO SP Status (Q600) message while in the Standby state in the event log for SP_TBD006 (184) days.*

4.1.3.2.2.2 Operational Data Verification

Upon receipt of each valid ATO Ex to ATO SP Status (Q600) message in the Standby state, the ATO SP calculates the CRC-32 value of each internally stored track data file listed within the ATO Ex to ATO SP Status (Q600) message. After ATO SP calculates the CRC-32 value of each internally stored track data file defined by ATO Ex, the ATO SP verifies the newly calculated track data file CRC-32 value matches the respective ATO Ex calculated track data file CRC-32 value.

When a discrepancy is detected between the ATO SP calculated track data file CRC-32 and the ATO Ex calculated track data file CRC-32, the ATO SP deletes the internally stored track data file and requests an updated track data file from ATO Ex. ATO Ex will respond to the track data request with the updated track data file contained within the Track Database Data (Q623) message. Upon receipt of the valid Track Database Data (Q623) message, ATO SP internally stores the updated track data file.

a) *Upon receipt of each valid ATO Ex to ATO SP Status (Q600) message in the Standby state, the ATO SP shall calculate the CRC-32 value of each internally stored track data file defined by ATO Ex.*

b) *After calculating the CRC-32 value of an internally stored track data file in the Standby state, the ATO SP shall verify the ATO SP calculated track data CRC-32 value matches the ATO Ex calculated track data CRC-32 value in the ATO Ex to ATO SP Status (Q600) message.*

c) *If ATO SP verifies there is a mismatch between the ATO SP calculated track CRC-32 value and the ATO Ex calculated track data CRC-32 value in the Standby state, ATO SP shall delete the internally stored track data file with the identified mismatch.*

d) *After ATO SP deletes an internally stored track data file due to a CRC-32 mismatch with ATO Ex in the Standby state, ATO SP shall send the Track Data Request (Q722) message to ATO Ex.*

e) *Upon receipt of a valid Track Database Data (Q623) message from ATO Ex in the Standby state, ATO SP shall internally store the track data file in the track repository.*

4.1.3.2.2.3 Current Position (Q610) Message

While SP is in the Standby state, SP receives the Current Position (Q610) message from ATO Ex. The SP uses the position data to establish the sensor point of reference on track as needed for the SP to transition to the Active state.

a) *When in the SP Standby state, the ATO SP shall accept valid Current Position (Q610) messages from ATO Ex.*

b) *When in the SP Standby state, the ATO SP shall reject invalid Current Position (Q610) messages from ATO Ex.*

c) *Upon receipt of each valid Current Position (Q610) message when in the SP Standby state, the ATO SP shall update the footage offset train position value in the internal* *current position dataset to the footage offset train position defined in the Current Position (Q610) message.*

d) *Upon receipt of each valid Current Position (Q610) message when in the SP Standby state,, the ATO SP shall update the time of receipt value in the internal current position dataset to the time of receipt the Current Position (Q610) message was received.*

e) *The ATO SP shall calculate the train's footage offset into a track segment to within +/- SP_TBD011 (1) feet of the train's actual footage offset into a track segment per every SP_TBD012 (100) feet travelled.*

4.1.3.2.2.4 Train Route (Q625) Message

Train route data defines the track segments and switch positions approximately 5 miles in front of the train and approximately 1 mile behind the train along the train's route. The ATO SP receives train route data from ATO Ex:

- Every SP_TBD014 (30) seconds
- Upon change to any of the calculated train route data (i.e., track segment or switch position)

Train route data is used to derive the foul volume as defined in Section 4.1.4.2.2. Upon receipt of each valid Train Route (Q625) message from ATO Ex, the ATO SP updates the track segments, switch positions, and time of receipt within the internally stored train route dataset. The ATO SP must store this data locally prior to transitioning to the Active state.

a) *When the ATO SP is in the Standby state, the ATO SP shall accept valid Train Route (Q625) messages from ATO Ex.*

b) *When the ATO SP is in the Standby state, the ATO SP shall reject invalid Train Route (Q625) messages from ATO Ex.*

c) *Upon receipt of each valid Train Route (Q625) message in the Standby state, the ATO SP shall update the track segment values in the internal train route dataset to the track segments defined in the Train Route (Q625) message.*

d) *Upon receipt of each valid Train Route (*Q625*) message in the Standby state, the ATO SP shall update the switch position values in the internal train route dataset to the switch positions defined in the Train Route (Q625) message.*

e) *Upon receipt of each valid Train Route (Q625) message in the Standby state, the ATO SP shall update the time of receipt value in the internal current position dataset to the time of receipt the Train Route (Q625) message was received.*

4.1.3.2.2.5 ATO Ex State Check

Upon receipt of a valid ATO Ex to ATO SP Status (Q600) message in the Standby state, SP verifies that ATO Ex is in the Unarmed Configured State. The ATO Ex must be in the ATO Ex Unarmed Configured state before the SP can transition to the SP Active state. If ATO Ex is in the ATO Ex Unarmed Configured State, SP may transition to the SP Active State upon successful completion of all other transition criteria. If ATO Ex is not in the ATO Ex Unarmed Configured State, SP will not transition to SP Active state.

a) *The SP verifies the most recent valid ATO Ex to ATO SP Status (Q600) message received in the Standby state has a "State" field = "Unarmed Configured."*

b) *The SP will not transition to the Active state if the most recent valid ATO Ex to ATO SP Status (Q600) message received in the Standby state does not have a "State" field = "Unarmed Configured."*

4.1.3.3 Standby State to Active State Transition Criteria

Several criteria must be satisfied before the SP can transition from Standby state to Active state. The SP transitions from the SP Standby state to the Active state only after all the following have been satisfied:

- Completed operational data synchronization with ATO Ex
- Receipt of a valid Train Route (Q625) message from ATO Ex
- SP verified the most recent valid ATO Ex to ATO SP Status (Q600) message received has a "State" field = "Unarmed Configured."

If one or more of the listed criteria is not satisfied, the SP will not transition to the Active state.

a) *The SP shall transition from the SP Standby state to the SP Active state after:*

  I. *Completed operational data synchronization with ATO Ex*

  II. *Receipt of a valid Train Route (Q625) message from ATO Ex*

  III. *The SP verified the most recent valid ATO Ex to ATO SP Status (Q600) message received has a "State*" field = "Unarmed Configured"

4.1.3.4 Standby State to Failed State Transition Criteria

The SP transitions to a failed state when a hardware or software failure is detected.

a) *Upon detection of a SP hardware failure in the Standby state, the SP shall transition to the Failed state.*

b) *Upon detection of a SP software failure in the Standby state, the SP shall transition to the Failed state.*

c) *Upon failure to receive a valid ATO Ex to ATO SP Status (Q600) message for SP_TBD004 (5) seconds after the previously received valid ATO Ex to ATO SP Status (Q600) message while in the Standby state, the SP shall transition to the Failed state.*

4.1.4 Active State

The SP performs the following function groups in parallel while in the Active state:

- ATO SP polling process
- Health monitoring process
- External environmental monitoring

Table A3 provides a description of each SP Active state function group.

Table A3. ATO SP Active State Function Group Descriptions

ATO SP Active State Process	Description
ATO SP polling process	The ATO SP receives ATO Ex status messages to perform integrity checks on track data and verify ATO Ex is in a state that supports ATO SP Active state processes. Additionally, the ATO SP sends the ATO SP status message to ATO Ex, to report OOI data generated as part of the external environmental monitoring process. The ATO SP polling process is defined in Section 4.1.4.1.
Health monitoring process	The ATO SP performs periodic self-tests to verify platform integrity, periodic diagnostics of sensor devices, review of sensor data reasonableness, and review of sensor data to identify degraded conditions through sense distance as defined in Section 4.1.4.3.
External environmental monitoring	The ATO SP assimilates current position data, train route data, and track data from ATO Ex to monitor the environment ahead of the lead locomotive of the train as defined in Section 4.1.4.2.

4.1.4.1 ATO SP Polling in the Active State

During the ATO SP polling process within the Active state, the ATO SP performs the following processes upon receipt of each valid ATO Ex to ATO SP Status (Q600) message:

- Dataset integrity checks on track data upon receipt of each valid ATO Ex to ATO SP Status (Q600) message (Section 4.1.4.1.2.3)
- Verification ATO Ex is in a state that supports ATO SP Active state processes upon receipt of each valid ATO Ex to ATO SP Status (Q600) message (Section 4.1.4.1.2.4)
- Updates the internal current position dataset upon receipt of each valid Current Position (Q610) message
- Updates the internal train route dataset upon receipt of each valid Train Route (Q625) message

The ATO SP continues polling with ATO Ex upon entry to the Active state. Polling between the two subsystems facilitates the exchange of the status message (i.e., heartbeat). The process for polling in the Active state is shown in Figure A10 below.

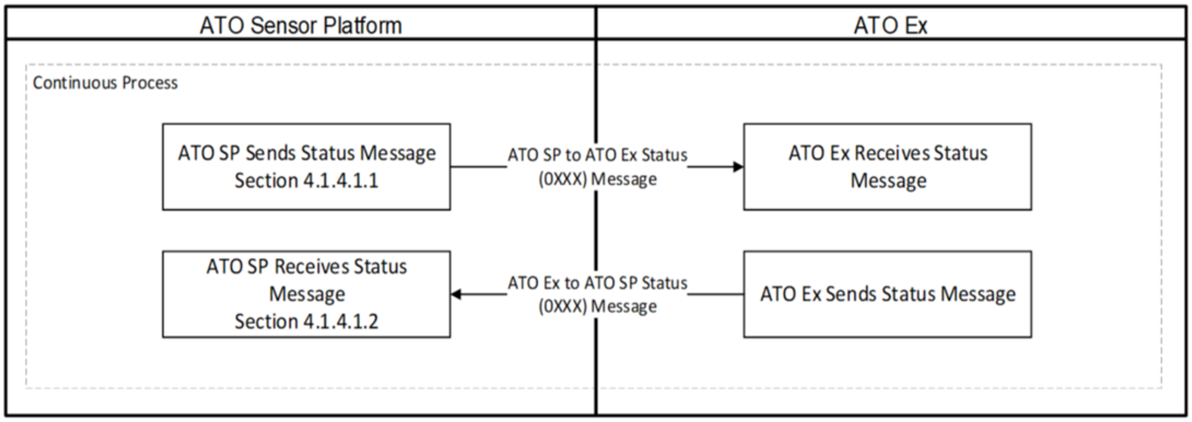

Figure A10. ATO SP Polling Activity in the Active State

4.1.4.1.1 ATO SP to ATO Ex Status (Q700) Message in the Active State

When the ATO SP is in the Active state, the ATO SP sends the ATO SP to ATO Ex Status (Q700) message every SP_TBD007 (1) seconds to provide ATO Ex with the following data obtained primarily through the external environmental monitoring process defined in Section 4.1.4.2:

- Current ATO SP state
- Sense distance
- Foul volume sense distance
- Foul volume clear distance
- The OOI/COI dataset

a) *The SP shall send the ATO SP to ATO Ex Status (Q700) message to the ATO Ex every SP_TBD007 (1) seconds while in the Active state.*

4.1.4.1.1.1 ATO SP to ATO Ex Status (Q700) Message Population in the Active State

Prior to sending each ATO SP to ATO Ex Status (Q700) message, SP populates the message fields with the following information:

- SP State = Active
- Active IRS Version = “Current IRS Version in Use”
- Preferred IRS Version = “Preferred IRS Version”
- Acceptable IRS Version = “Acceptable IRS Version”
- For each Track Data on the train’s intended route:
  - Railroad SCAC = “Railroad SCAC of the railroad providing the track data”
  - Subdivision/District ID = “PTC Subdivision/District ID”
  - Track Data Version = “Version of Track Data”

- Track CRC = "Current Track Data CRC-32 Calculation"

- Sense Distance = "Current sense distance calculation"
- Foul Volume Sense Distance = "Current foul volume sense distance calculation"
- Foul Volume Clear Distance = "Current foul volume clear distance calculation"
- OOI/COI List = "Current OOI/COI dataset"

a) For each ATO SP to ATO Ex Status (Q700) message in the Active state, the SP shall populate the SP State field = Active.

b) For each ATO SP to ATO Ex Status (Q700) message in the Active state, the SP shall populate the Active IRS Version field = "current IRS version in use by SP."

c) For each ATO SP to ATO Ex Status (Q700) message in the Active state, the SP shall populate the Preferred IRS Version field = "preferred IRS version number."

d) For each ATO SP to ATO Ex Status (Q700) message in the Active state, the SP shall populate the Acceptable IRS Version field = "acceptable IRS version number."

e) For each ATO SP to ATO Ex Status (Q700) message in the Active state, the SP shall populate the Railroad SCAC field = "Railroad SCAC of the railroad providing the track data" for each track data on the train's intended route.

f) For each ATO SP to ATO Ex Status (Q700) message in the Active state, the SP shall populate the Subdivision/District ID field = "PTC Subdivision/District ID" for each track data on the train's intended route.

g) For each ATO SP to ATO Ex Status (Q700) message in the Active state, the SP shall populate the Track Data Version field = "version of track data" for each track data on the train's intended route.

h) For each ATO SP to ATO Ex Status (Q700) message in the Active state, the SP shall populate the Track CRC field = "current track data CRC-32 calculation" for each track data on the train's intended route.

i) For each ATO SP to ATO Ex Status (Q700) message in the Active state, the SP shall populate the Sense Distance field = "current sense distance calculation."

j) For each ATO SP to ATO Ex Status (Q700) message in the Active state, the SP shall populate the Foul Volume Sense Distance field = "current foul volume sense distance calculation."

k) For each ATO SP to ATO Ex Status (Q700) message in the Active state, the SP shall populate the Foul Volume Clear Distance field = "current foul volume clear distance calculation."

l) For each ATO SP to ATO Ex Status (Q700) message in the Active state, the SP shall populate the OOI/COI List fields = "current OOI/COI dataset."

4.1.4.1.2 ATO Ex to ATO SP Status (Q600) Message in the ATO SP Active State

The SP receives the ATO Ex to ATO SP Status (Q600) message in the SP Active state to maintain a heartbeat with the ATO Ex. Upon receipt of each ATO Ex to ATO SP Status (Q600) message, the SP verifies the integrity of the ATO Ex to ATO SP Status (Q600) message as defined in [ATO Ex – ATO SP IRS] that includes acceptable range of values, message completeness, and acceptable receive time. The following subsections define the specific ATO SP functions performed upon receipt of valid ATO Ex to ATO SP (Q600) messages while in the Active state.

a) *The SP shall accept valid ATO Ex to ATO SP Status (Q600) messages from the ATO Ex while in the Active state.*

The SP shall reject invalid ATO Ex to ATO SP Status (Q600) messages while in the Active state.

4.1.4.1.2.1 Failure to Receive Valid ATO Ex to ATO SP Status (Q600) Message in the ATO SP Active State

If the SP fails to receive a valid ATO Ex to ATO SP Status (Q600) message for SP_TBD008 (5) seconds after the previously received valid ATO Ex to ATO SP Status (Q600) message, the SP aborts the Active state and transitions to the SP Failed state.

a) *The SP shall transition from the Active state to the Failed state if the SP fails to receive a valid ATO Ex to ATO SP Status (Q600) message for SP_TBD008 (5) seconds after the previously received valid ATO Ex to ATO SP Status (Q600) message.*

4.1.4.1.2.2 Internal Record of Failure to Receive Valid ATO Ex to ATO SP Status (Q600) Message in ATO Ex Active State

To support local diagnostics, the SP internally records the failure to receive a valid ATO Ex to ATO SP Status (Q600) message for SP_TBD008 (5) seconds after the previously received valid ATO Ex to ATO SP Status (Q600) message in the SP Active state, or when the SP rejects an ATO Ex to ATO SP Status (Q600) message while in the SP Active state.

a) *If the SP fails to receive a valid ATO Ex to ATO SP Status (Q600) message for SP_TBD008 (5) seconds after the previously received valid ATO Ex to ATO SP Status (Q600) message while in the SP* Active *state, the SP shall internally record the failure to receive a valid ATO Ex to ATO SP Status (Q600) message in the event log.*

4.1.4.1.2.3 Track Data Integrity Check

Upon receipt of each valid ATO Ex to ATO SP Status (Q600) message in the Active state, the ATO SP calculates the CRC-32 value of each internally stored track data file listed within the ATO Ex to ATO SP Status (Q600) message. After ATO SP calculates the CRC-32 value of each internally stored track data file defined by ATO Ex, the ATO SP verifies the newly calculated track data file CRC-32 value matches the respective ATO Ex calculated track data file CRC-32 value.

When a discrepancy is detected between the ATO SP calculated track data file CRC-32 and the ATO Ex calculated track data file CRC-32, the ATO SP deletes the internally stored track data file and requests an updated track data file from ATO Ex. ATO Ex will respond to the track data request with the updated track data file contained within the Track Database Data (Q623) message. Upon receipt of the valid Track Database Data (Q623) message, ATO SP internally stores the updated track data file.

a) Upon receipt of each valid ATO Ex to ATO SP Status (Q600) message in the Active state, the ATO SP shall calculate the CRC-32 value of each internally stored track data file defined by ATO Ex.

b) After calculating the CRC-32 value of an internally stored track data file in the Active state, the ATO SP shall verify the ATO SP calculated track data CRC-32 value matches the ATO Ex calculated track data CRC-32 value in the ATO Ex to ATO SP Status (Q600) message.

c) If ATO SP verifies there is a mismatch between the ATO SP calculated track CRC-32 value and the ATO Ex calculated track data CRC-32 value in the Active state, ATO SP shall delete the internally stored track data file with the identified mismatch.

d) After ATO SP deletes an internally stored track data file due to a CRC-32 mismatch with ATO Ex in the Active state, ATO SP shall send the Track Data Request (Q722) message to ATO Ex.

e) Upon receipt of a valid Track Database Data (Q623) message from ATO Ex in the Active state, ATO SP shall internally store the track data file in the track repository.

4.1.4.1.2.4 ATO Ex State Check

Upon receipt of each valid ATO Ex to ATO SP Status (Q600) message in the Active state, ATO SP verifies that ATO Ex is in a state which requires the ATO SP to remain in the Active state. If ATO Ex is in a state which does not require the SP to be in Active state, the SP transitions to the SP Standby state. The ATO Ex states requiring the SP to transition to Standby state are covered in the transition criteria section.

a) The SP shall verify the most recent valid ATO Ex to ATO SP Status (Q600) message received has a "State" field which requires the SP in the Active state.

b) Upon receipt of a valid ATO Ex to ATO SP (Q600) message in the Active state, the SP shall record the ATO Ex state in the event log.

4.1.4.1.2.5 Current Position Data

The ATO SP receives the Current Position (Q610) message from ATO Ex every SP_TBD009 (1) seconds or every SP_TBD010 (100) feet of change in distance travelled by the train. The current train position is defined in terms of a footage offset into a track segment allowing the ATO SP to reference the track data file associated with the track segment to define the absolute position of the ATO train. Upon receipt of each valid Current Position (Q610) message from ATO Ex, the ATO SP updates the train position and time of receipt within the internally stored current position dataset. Additionally, the ATO SP calculates the train's footage offset into a track segment to within SP_TBD011 (1) feet of the train's actual footage offset into a track segment per every SP_TBD012 (100) feet travelled by the train. The Current Position (Q610) message is used to re-establish the absolute position of the ATO train to account for calculation errors.

a) When the ATO SP is in the Active state, the ATO SP shall accept valid Current Position (Q610) messages from ATO Ex.

b) *When the ATO SP is in the Active state, the ATO SP shall reject invalid Current Position (Q610) messages from ATO Ex.*

c) *Upon receipt of each valid Current Position (Q610) message, the ATO SP shall update the footage offset train position value in the internal current position dataset to the footage offset train position defined in the Current Position (Q610) message.*

d) *Upon receipt of each valid Current Position (Q610) message, the ATO SP shall update the time of receipt value in the internal current position dataset to the time of receipt the Current Position (Q610) message was received.*

e) *The ATO SP shall calculate the train's footage offset into a track segment to within +/- SP_TBD011 (1) feet of the train's actual footage offset into a track segment per every SP_TBD012 (100) feet travelled.*

4.1.4.1.2.5.1 Failure to Receive Current Position Data

If the ATO SP fails to receive a valid Current Position (Q610) message for SP_TBD013 (5) seconds, the ATO SP internally logs the failure and transitions from the Active state to the Failed state due to an inability to reliably establish an ITC-PTC-level resolution of absolute train position.

a) *If the ATO SP fails to receive a valid Current Position (Q610) message for SP_TBD013 (5) seconds, the ATO SP shall internally log the failure to receive the Current Position (Q610) message while in the Active state.*

b) *If the ATO SP fails to receive a valid Current Position (Q610) message for SP_TBD013 (5) seconds, the ATO SP shall transition from the Active state to the Failed state.*

4.1.4.1.2.6 Train Route Data

Train route data defines the track segments and switch positions approximately 5 miles in front of the train and approximately 1 mile behind the train along the train's route. The ATO SP receives train route data from ATO Ex:

- Every SP_TBD014 (30) seconds, or
- Upon change to any of the calculated train route data (i.e., track segment or switch position).

Train route data is used to derive the foul volume as defined in Section 4.1.4.1.2.6. Upon receipt of each valid Train Route (Q625) message from ATO Ex, the ATO SP updates the track segments, switch positions, and time of receipt within the internally stored train route dataset.

a) *When the ATO SP is in the Active state, the ATO SP shall accept valid Train Route (Q625) messages from ATO Ex.*

b) *When the ATO SP is in the Active state, the ATO SP shall reject invalid Train Route (Q625) messages from ATO Ex.*

c) *Upon receipt of each valid Train Route (Q625) message in the Active state, the ATO SP shall update the track segment values in the internal train route dataset to the track segments defined in the Train Route (Q625) message.*

d) *Upon receipt of each valid Train Route (Q625) message in the Active state, the ATO SP shall update the switch position values in the internal train route dataset to the switch positions defined in the Train Route (Q625) message.*

e) *Upon receipt of each valid Train Route (Q625) message in the Active state, the ATO SP shall update the time of receipt value in the internal current position dataset to the time of receipt the Train Route (Q625) message was received.*

4.1.4.1.2.6.1 Failure to Receive Train Route Data

If the ATO SP fails to receive a valid Train Route (*Q625*) message for SP_TBD015 seconds, the ATO SP internally logs the failure and transitions from the Active state to the Failed state.

a) *If the ATO SP fails to receive a valid Train Route (Q625) message for SP_TBD015 seconds, the ATO SP shall internally log the failure to receive the Train Route (Q625) message while in the Active state.*

b) *If the ATO SP fails to receive a valid Train Route (Q625) message for SP_TBD015 seconds, the ATO SP shall transition from the Active state to the Failed state*

4.1.4.2 External Environmental Monitoring

The SP monitors external temperature and the operating environment ahead of the train. Operating regions of interest monitored by the SP are:

- Foul volume
- Wayside
- Track and road structures

The SP monitors these regions for objects condition conditions that present hazards to which a train response may be needed.

The SP maintains a dataset of OOI and COI information as needed by ATO Ex to initiate train responses. Additionally, the SP records and stores time stamped data from individual sensor devices for offboard use.

Figure A11 shows a breakdown of external environment monitoring functions.

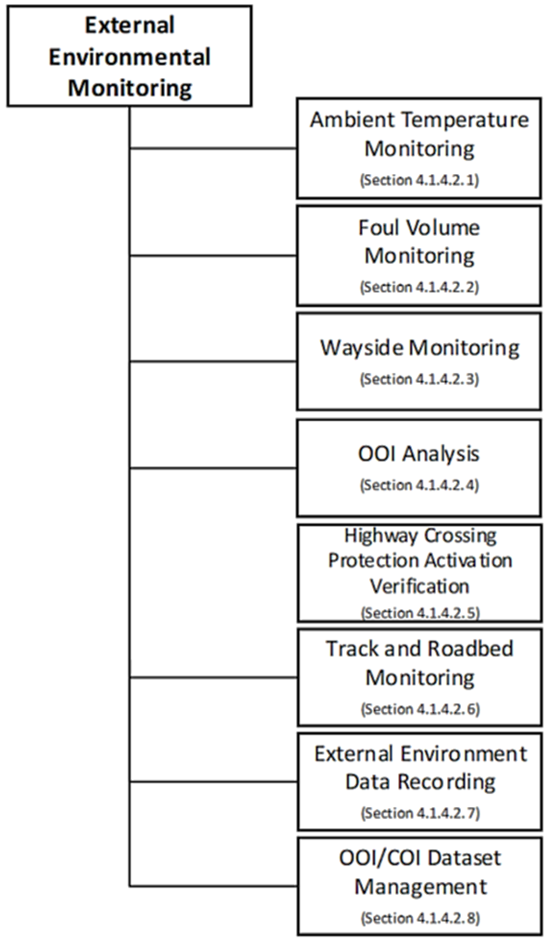

Figure A11. External Environment Monitoring Functions

4.1.4.2.1 Ambient Temperature Monitoring

Ambient temperature monitoring and reporting provides ATO Onboard with the information required to initiate the correct train response when external temperature is sufficiently low to require brake conditioning to ensure safe train handling.

a) *The SP shall quantify the ambient external temperature at the lead locomotive.*

b) *The SP shall quantify the ambient external temperature at the lead locomotive in degrees Fahrenheit.*

c) *The SP shall quantify the ambient external temperature at a minimum rate of SP_TBD016 (1)/minute.*

d) *The SP shall quantify the ambient external temperature at the lead locomotive with a maximum error of SP_TBD017 (2) degrees Fahrenheit.*

4.1.4.2.2 Foul Volume Monitoring

The SP monitors the foul volume for obstructions.

4.1.4.2.2.1 SP Foul Volume

The foul volume is the three-dimensional volume relative to the position of the train and extending ahead of the train and along the intended route of the train within which OOIs may collide with the train. The length of the Foul Volume is equal to the sense distance of the SP. Sense Distance is the maximal distance that the SP can detect objects as measured from the leading edge of the lead locomotive. The sense distance is derived by the SP through analysis of sensor data. Sense Distance may be affected by adverse weather conditions and natural obstructions such as dense foliage and mountainous terrain.

The SP derives the foul volume from:

- Track data (synchronized with ATO Ex)
- Intended train route
- Position of the train on track

The synchronization of data with ATO Ex is defined in Sections 4.1.3.2.2.2, 4.1.3.2.2.3, and 4.1.3.2.2.4.

The SP provides correction to align the derived foul volume with the actual centerline of the track.

Note: Processes for SP correction of foul volume, possibly using observed location of track and/or interpolation of train position on track needs to be included in decomposition of SP functions.

a) *The width of the Foul Volume monitored by the SP shall extend SP_TBC01 (4) ft. to either side of the centerline of the track occupied by the train.*

b) *The height of the Foul Volume monitored by the SP shall extend from the roadbed to SP_TBC02 (20) ft. above the roadbed of the track occupied by the train.*

c) *The SP sense distance of the Foul Volume shall be no less than SP_TBD018 (4,000) ft. along the track centerline of level tangent track in all lighting conditions free of obfuscating conditions (e.g., rain, snow, fog, blowing dust, etc.).*

d) *The SP shall calculate Foul Volume sense distance at a rate of SP_TBD019 (1)/seconds.*

e) *The SP shall calculate Foul Volume Sense Distance with an error of no greater than SP_TBD020 (5) %.*

4.1.4.2.2.2 OOI Detection Within the Foul Volume

The SP detects OOIs within the foul volume that may present a hazard to the train.

a) *The SP shall detect OOIs within the Foul Volume ahead of the train.*

b) *The SP shall detect OOIs with a height of SP_TBD021 (12) inches or greater above the roadbed.*

c) *The SP shall detect OOIs with a width of SP_TBD022 (12) inches or greater.*

d) *The SP shall detect OOIs with a length of SP_TBD023 (12) inches or greater.*

e) *The SP shall have a missed OOI detection rate of less than SP_TBD024 events per operating hour.*

f) *The SP shall have a false OOI detection rate of less than SP_TBD025 events per operating hour.*

g) *The SP shall detect an OOI within SP_TBD028 (1) seconds of entering the SP Foul Volume.*

4.1.4.2.2.3 OOI Ranging within the Foul Volume

The SP quantifies the range to each OOI detected within the foul volume.

a) *The SP shall quantify the distance from the leading edge of the lead locomotive to each detected OOI within the foul volume along the intended route of the train.*

b) *The SP shall quantify the distance from the leading edge of the train to detected OOIs with a maximum error of SP_TBD029 (1) feet per 1,000 ft.*

4.1.4.2.2.4 Foul Volume Clear Distance Monitoring

The SP quantifies the distance of from the leading edge of the lead locomotive along the track centerline of the intended route that the Foul Volume is clear of OOIs. The clear distance is the distance from the leading edge of the lead locomotive to the nearest OOI that may present a hazard to the train.

a) *The SP shall quantify the clear distance as the distance ahead of the train along the intended route for which no hazard OOIs are detected.*

b) *The SP shall quantify the clear distance as the distance ahead of the train along the intended route for which no hazard OOIs are predicted to be within the foul volume.*

c) *The SP shall quantify the clear distance with a maximum error of SP_TBD040 (1) feet per 1,000 ft.*

d) *The SP update the clear distance a minimum rate of SP_TBD041 (1)/second.*

4.1.4.2.2.5 Collision Detection

The collision volume is a subset of the foul volume that spans from the leading edge of the lead locomotive to SP_TBD042 (6) ft. ahead of the train. A collision is assumed to have occurred whenever an OOI is detected within the collision volume and current train speed is greater than SP_TBD043 (0) mph.

a) *The SP shall detect OOIs that are present within the Collision Volume.*

b) *The SP shall calculate a classification for the OOI involved in the collision.*

c) *The SP shall have a failed collision detection rate of less than SP_TBD044 events per operating hour.*

d) *The SP shall have a false collision detection rate of less than SP_TBD045 events per operating hour.*

4.1.4.2.3 Wayside Monitoring

The Wayside is the volume extending *SP_TBC03 (20)* feet to either side of the foul volume of the train. The SP monitors the Wayside for OOIs that may present hazards or require a train response.

a) *The SP shall monitor the Wayside ahead of the train along the intended route for OOIs.*

b) *The width of the Wayside volume monitored by the SP shall extend* a minimum of *SP_TBC03 (20) ft. to either side of the Foul Volume.*

c) *The length of the Wayside volume monitored by the SP shall extend from the leading edge of the lead locomotive along the track centerline of the intended route of the train to a distance equal to the maximum Foul Volume sense distance*

4.1.4.2.3.1 OOI Detection Within the Wayside

The SP detects OOIs within the Wayside that may present a hazard to the train or require a train response.

a) *The SP shall detect OOIs within the Wayside ahead of the train.*

b) *The SP shall detect OOIs with a height of SP_TBD046 (12) inches or greater above the roadbed.*

c) *The SP shall detect OOIs with a width of SP_TBD047 (12) inches or greater.*

d) *The SP shall detect OOIs with a length of SP_TBD048 (12) inches or greater.*

e) *The SP Shall detect OOIs within the Foul Volume of an adjacent track.*

f) *The SP shall provide a minimum OOI detection range of SP_TBD049 (4,000) ft. at train speeds of SP_TBD050 (20) mph or less.*

g) *The SP shall have a missed OOI detection rate within the Wayside of less than SP_TBD051 events per operating hour.*

h) *The SP shall have a false OOI detection rate within the Wayside of less than SP_TBD052 events per operating hour.*

i) *The SP shall detect an OOI within SP_TBD055 (1) seconds of entering the Wayside.*

4.1.4.2.3.2 OOI Ranging Within the Wayside

The SP quantifies the range to each OOI detected within the Wayside.

a) *The SP shall quantify the distance from the leading edge of the lead locomotive to each detected OOI within the Wayside along the track centerline of the intended route of the train.*

b) *The SP shall quantify the distance from the leading edge of the train to detected OOIs with a maximum error of SP_TBD056 (1) feet per 1,000 ft.*

4.1.4.2.4 OOI Analysis

4.1.4.2.4.1 OOI Classification

OOI classification is necessary to decide if it is safe for the train to proceed or if a train response is required. Different classifications result in different responses. OOIs classification include humans, vehicles, livestock, and rolling stock. These are items that have specific operating rule requirements associated with them.

a) *The SP shall classify each detected OOI.*

b) *The SP shall assign a classification listed in Table A4 to each detected OOI.*

Table A4. OOI Classifications

OOI Classification
Person
Vehicle
Rolling Stock
Livestock
Non-Hazard
Unknown

c) *The SP shall assign a confidence level for each detected OOI classification.*

d) *The SP shall assign a false classification of "Non-Hazard" to a "Person" at a rate of less than SP_TBD035 events per operating hour.*

e) *The SP shall assign a false classification of "Non-Hazard" to a "Vehicle" at a rate of less than SP_TBD036 events per operating hour.*

f) *The SP shall assign a false classification of "Non-Hazard" to "Rolling Stock" at a rate of less than SP_TBD037 events per operating hour.*

g) *The SP shall assign a false classification of "Non-Hazard" to an "Unknown" at a rate of less than SP_TBD038 events per operating hour.*

h) *The SP shall assign a false classification of "Non-Hazard" to "Livestock" at a rate of less thanSP_TBD039 events per operating hour.*

i) *If the SP is unable to assign an explicit classification to a detected OOI, that detected OOI shall be assigned a classification of "Unknown."*

4.1.4.2.4.2 OOI Intercept Prediction

The SP calculations a prediction of the future position of OOIs within the foul volume and wayside in terms of trajectory prediction intervals. OOI future position prediction is used by the ATO Ex to initiate predictive train responses.

a) *The SP shall calculate a trajectory prediction for detected OOIs.*
b) *The SP shall identify a detected OOI as a Potential Intercept when that OOI's SP_TBC04 (0.99) trajectory prediction interval intersects the predicted location of any portion of the leading edge of the lead locomotive along the intended route.*
c) *The SP shall calculate Potential Intercept Distance for each OOI having a Potential Intercept.*
d) *The SP shall calculate the Potential Intercept Distant from the leading edge of the lead locomotive to the nearest location along the intended route at which the SP_TBC04 (0.99) trajectory prediction interval of the OOI intersects the foul volume of the predicted location of the leading edge of the lead locomotive.*
e) *The SP shall update the Potential Intercept indicator for each detected OOI at a minimum rate of SP_TBD062 (1)/second.*
f) *The SP shall update the Potential Intercept Distance for each detected OOI identified as a Potential Intercept at a minimum rate of SP_TBD063 (1)/second.*

4.1.4.2.5 Highway Crossing Protection Activation Verification

When a train enters an active highway/rail grade crossing that is protected by crossing gates, the SP observes the position of the crossing gates.

a) *The SP shall use the track database to determine locations of gated highway crossing systems.*
b) *The SP shall monitor the Wayside ahead of the train along the intended route for highway crossing protection systems.*
c) *The SP shall detect highway crossing protection system warning gates that are not in a horizontal position as defined in 49 CFR § 234.5.*
d) *If SP detects crossing gates that are not in the horizontal position, SP shall report the crossing as failed.*
e) *The SP shall detect if the gate arms are in the activated position TBD seconds prior to entry of the leading edge of the lead locomotive into the protected highway rail interface.*
f) *If the SP fails to detect the position of crossing gates, SP shall report the crossing as failed.*
g) *The SP shall have a failed Crossing Gate Activation Verification Classification rate of less than SP_TBD064 events per operating hour.*
h) *The SP shall have a false Crossing Gate Activation Verification Classification rate of less than SP_TBD065 events per operating hour.*

4.1.4.2.6 Track and Roadbed Monitoring

The SP monitors the track and roadway AOI for track structural conditions that present a hazard to the safe passage of the train.

4.1.4.2.6.1 Switch Alignment Monitoring

ATO Ex provides the SP with a track data file that includes the location of switches along the intended route of the train. When approaching a switch, the SP detects the position of that switch and reports it to ATO Ex.

a) *The SP shall classify the alignment position of switches along the intended route of the train.*

b) *The SP shall assign each detected switch an identifier as given in the onboard track database.*

c) *The SP shall maintain a list of each detected switch.*

d) *The SP shall classify the alignment position of each detected switch as "Normal," "Reverse," or "Unknown."*

e) *The SP shall have a misclassification of the switch position at a rate not to exceed SP_TBD066 events/operating hour when train speed is less than or equal to 20 mph. (Note: "Unknown" is considered a misclassification.)*

f) *The SP shall classify the switch position when the train is operating at a speed of less than or equal to SP_TBD067 (20) mph at a minimum distance of SP_TBD068 (150) ft. from the switch.*

4.1.4.2.6.2 Fusee Detection

Fusees are used to alert trains to potential hazards in the foul volume or Wayside. The SP detects fusees and reports their detection to ATO Ex.

a) *The SP shall monitor the Track and Roadbed ahead of the train along the intended route for fusees.*

b) *The SP shall monitor the Wayside ahead of the train along the intended route for fusees.*

c) *The SP shall assign a unique identifier to each detected fusee.*

d) *The SP shall maintain a record of each detected fusee.*

e) *The SP shall calculate the distance from each detected fusee to the leading edge of the lead locomotive along the track centerline of the intended route with an error of less than SP_TBD069 (5) %.*

f) *The SP shall classify a fusee as applicable to the train if the fusee is located in the Foul Volume along the intended route.*

g) *The SP shall classify a fusee as applicable to the train if the fusee is located in the Wayside along the intended route with no adjacent track.*

h) *The SP shall classify a fusee as applicable if the fusee is located in the Wayside with adjacent track and the fusee is on the near side of the first rail of the adjacent track.*

i) *The SP shall have a failed fusee detection rate of less than SP_TBD071 events per operating hour.*

j) *The SP shall have a false fusee applicability classification rate of less than SP_TBD072 events per operating hour.*

4.1.4.2.6.3 Track Condition Monitoring

The SP shall monitor the roadbed ahead of the train along the intended route for hazardous Track and Roadbed Condition.

a) *The SP shall assign a unique identifier to each detected hazardous Track and Roadbed Condition.*

b) *The SP shall maintain a record of each detected hazardous Track and Roadbed Condition.*

c) *The SP shall classify each detected hazardous Track and Roadbed Condition per Table A5.*

Table A5. Track and Roadbed Condition Classifications

Track and Roadbed Condition
Unsupported Ties
Unexpected Track Curvature
Unexpected Track Grade
Excessive Track Gage
Water Over Rail
Snow Over Rail
Earth or Rock Over Rail

4.1.4.2.6.3.1 Unsupported Ties

a) *The SP shall monitor the roadbed ahead of the train along the intended route for two or more consecutive unsupported ties.*

b) *The SP shall calculate the distance from the leading edge of the lead locomotive to the nearest location along the intended route of the train at which two or more consecutive ties are unsupported.*

c) *The SP shall calculate the distance from the leading edge of the lead locomotive to the nearest location along the intended route of the train at which two or more consecutive ties are unsupported with an error of no greater than SP_TBD058 (5) %.*

d) *The SP shall update the distance from the leading edge of the lead locomotive to the nearest location along the intended route of the train at which two or more consecutive ties are unsupported at a minimum rate of SP_TBD059 (1)/second.*

e) *The SP shall have a failed Unsupported Ties detection rate of less than* SP_*TBD075 events per operating hour.*

4.1.4.2.6.3.2 Unexpected Track Curvature

Unexpected track curvature is curvature in the track that deviates from track curve defined in the track data file provided by ATO Ex. Deviation in track curvature could be indicative of thermal misalignment or other roadbed problems that may present a hazard to a train operating over that segment of track. The SP detects track curvature ahead of the train.

a) *The SP shall monitor the roadbed ahead of the train along the intended route for track curvature that deviates from the Expected Track Curvature as stored in the onboard track data.*

b) *The SP shall calculate the amount of deviation of Detected Track Curvature along the intended route of the train from the Expected Track Curvature, as stored in the onboard track data, in degrees of track curvature (degrees per 100 ft. of track centerline).*

c) *The SP shall calculate the amount of deviation of Detected Track Curvature along the intended route of the train from the Expected Track Curvature, as stored in the onboard track data, with an error of no greater than SP_TBD076 (5).*

d) *The SP shall calculate the distance from the leading edge of the lead locomotive to the nearest location along the intended route of the train at which Detected Track Curvature deviates from Expected Track Curvature, as stored in the onboard track data, with an error of no greater than SP_TBD077 (X) feet per 1,000 feet.*

e) *The SP shall update the distance from the leading edge of the lead locomotive to the nearest location along the intended route of the train at which Detected Track Curvature deviates from Expected Track Curvature, as stored in the onboard track data, at a minimum rate of SP_TBD078 (1)/second.*

f) *The SP shall fail to detect a track curvature along the intended route of the train that deviates from Expected Track Curvature, as stored in the stored in the onboard track data, at a rate of less than SP_TBD079 events per operating hour.*

4.1.4.2.6.3.3 Unexpected Track Grade

Unexpected track grade is vertical rise/drop of the track that deviates from track grade defined in the track data file provided by ATO Ex. Deviation in track grade could be indicative of roadbed problems that may present a hazard to a train operating over that segment of track. The SP detects track grade ahead of the train.

a) *The SP shall monitor the roadbed ahead of the train along the intended route for track grade that deviates from the Expected Track Grade as stored in the onboard track data.*

b) *The SP shall calculate the amount of deviation of Detected Track Grade along the intended route of the train from the Expected Track Grade, as stored in the onboard track data, in units of percent grade.*

c) *The SP shall calculate the amount of deviation of Detected Track Grade along the intended route of the train from the Expected Track Grade, as stored in the onboard track data, with an error of no greater than SP_TBD080 (0.1) percent grade (feet per 100 feet).*

d) *The SP shall calculate the distance from the leading edge of the lead locomotive to the nearest location along the intended route of the train at which Detected Track Grade deviates from Expected Track Grade, as stored in the onboard track data, with an error of no greater than SP_TBD081 (5) %.*

e) *The SP shall update the distance from the leading edge of the lead locomotive to the nearest location along the intended route of the train at which Detected Track Grade deviates from Expected Track Grade, as stored in the onboard track data, at a minimum rate of SP_TBD082 (1)/second.*

f) *The SP shall fail to detect a track grade along the intended route of the train that deviates from Expected Track Grade, as stored in the stored in the onboard track data, at a rate of less than SP_TBD083 events per operating hour.*

4.1.4.2.6.3.4 Water Over Rail

Water over the rail may mask damage to the roadbed. Operation of a train through water deep enough to cover the railhead may also result in damage to various locomotive components (i.e., traction motors, roller bearings, etc.). The SP detects water over the rail along the intended route of the train.

a) *The SP shall monitor the Track and Roadbed ahead of the train along the intended route for water above one or both rails.*

b) *The SP shall fail to detect water over one or both rails ahead of the train along the intended route at a rate of less than SP_TBD092 events per operating hour.*

4.1.4.2.6.3.5 Snow Over Rail

Accumulations of snow, especially on mountain grades, presents potential hazards that need to be addressed through changes to train handling such as reduced train speed and periodic conditioning of train brakes. The SP detects snow over the rail along the intended route of the train.

a) *The SP shall monitor the Track and Roadbed ahead of the train along the intended route for snow covering one or both rails.*

b) *The SP shall fail to detect snow covering one or both rails ahead of the train along the intended route at a rate of less than SP_TBD096 events per operating hour.*

4.1.4.2.6.3.6 Earth or Rock Over Rail

Earth or rock over the rail presents a derailment hazard if a train operates over that segment of track. The SP detects earth or rock over the rail along the intended route of the train.

a) *The SP shall monitor the Track and Roadbed ahead of the train along the intended route for earth or rock covering one or both rails.*

b) *The SP shall fail to detect earth or rock covering one or both rails ahead of the train along the intended route at a rate of less than SP_TBD100 events per operating hour.*

4.1.4.2.6.3.7 Fire

a) *The SP shall monitor the Foul Volume, Wayside, and Track and Roadbed ahead of the train along the intended route for the existence of fire.*

b) *The SP shall detect fire in the Foul Volume, Wayside, and Track and Roadbed ahead of the train along the intended route.*

c) *The SP shall classify each detected fire in the Foul Volume, Wayside, and Track and Roadbed ahead of the train along the intended route per Table A6.*

Table A6. Fire Classifications

Fire Classification
Tie
Wayside
Bridge
Tunnel
Undetermined

d) *The SP shall calculate the temperature of detected fires in degrees Fahrenheit.*

e) *The SP shall calculate the distance from the leading edge of the lead locomotive to the nearest location along the intended route of the train to the detected fire.*

f) *The SP shall calculate the distance along the intended route of the train in which fire exists.*

g) *The SP shall calculate the distance from the leading edge of the lead locomotive to the nearest location along the intended route of the train to the detected fire with an error no greater than SP_TBD101 (5) %.*

h) *The SP shall calculate the distance along the intended route of the train in which fire exists with an error of no greater than SP_TBD102 (5) %*

i) *The SP shall update the distance from the leading edge of the lead locomotive to the nearest location along the intended route of the train to the detected fire at a minimum rate of SP_TBD103 (1)/second.*

j) *The SP shall update the distance along the intended route of the train in which fire exists at a minimum rate of SP_TBD104 (1)/second.*

k) *The SP shall have a failed Fire detection rate of less than SP_TBD105 events per operating hour.*

4.1.4.2.7 Sensor Data Record

While in the Active state, the SP records raw sensor data in the sensor data log. Data to be stored includes, but is not limited to raw sensor data, detected OOI data, and detected COI data.

a) *The SP shall record SP_TBD106 (24) hours of raw sensor data in a raw sensor data log.*

b) *SP raw sensor data recorded in the sensor data log shall include time reference.*

c) *SP raw sensor data recorded in the sensor data log shall include position reference.*

d) *The SP shall record SP_TBD107 (24) hours of detected OOI data in a SP detection data log.*

e) *SP detected OOI data recorded in the sensor data log shall include time reference.*

f) *SP detected OOI data recorded in the sensor data log shall include position reference.*

g) *The SP shall record SP_TBD107 (24) hours of detected COI data in a SP detection data log.*

h) *SP detected COI data recorded in the sensor data log shall include time reference.*

i) *SP detected COI data recorded in the sensor data log shall include position reference.*

4.1.4.2.8 OOI/COI Dataset Management

The SP internally stores a record of each OOI detected within the foul volume, wayside, and track and roadbed within the OOI/COI Dataset. Each OOI is assigned a unique identifier and remains in the OOI/COI Dataset until SP_TBD0349 seconds after the leading edge of the train passes the OOI location. For each OOI in the OOI/COI Dataset, the SP records and periodically updates the distance to the OOI, the classification of the OOI, the confidence of the OOI classification, an indication of predicted intercept with the train, predicted intercept distance, and AOI indicator (i.e., foul volume, wayside, or foul volume of adjacent track).

a) *Upon initial detection of an OOI, the SP shall assign a unique identifier to the OOI*

b) *Upon initial detection of an OOI, the SP shall record the OOI in the OOI/COI Dataset*

c) *Within the OOI/COI Dataset, the SP shall record each OOI's:*

d) *Unique OOI identifier*

e) *Distance to OOI (Sections 4.1.4.2.2.3 and 4.1.4.2.3.2)*

f) *Classification of OOI (Section 4.1.4.2.4.1)*

g) *OOI intercept distance (Section 4.1.4.2.4.2)*

h) *OOI detection zone*

i) *The SP shall remove an OOI from the OOI/COI Dataset until SP_TBD0349(30) seconds* after *the leading edge of the train passes the detected OOI location.*

j) *The SP shall assign a unique identifier to each detected OOI within SP_TBD0031(1) second of initial detection.*

k) *If the OOI was detected within the Foul Volume, the SP shall assign the OOI detection zone as "Foul Volume."*

l) *If the OOI was detected within the wayside, the SP shall assign the OOI detection zone as "Wayside."*

m) If the OOI was detected within the Foul Volume of an adjacent track, the SP shall assign the OOI detection zone as "Foul Volume – Adjacent Track."

n) The SP shall update the internal record of OOIs in the OOI/COI Dataset at a minimum rate of SP_TBD03091(1) second.

4.1.4.3 Health Monitoring

The SP monitors the integrity of the SP hardware and SP software when in the SP Active state. Any SP hardware or SP software failure will cause a transition to the Failed state.

a) The SP shall conduct system HW integrity monitoring at an interval of no less than SP_TBD108 (60) seconds while in the SP Active state.

b) The SP shall conduct system SW integrity monitoring at an interval of no less than SP_TBD108 (60) seconds while in the SP Active state.

4.1.4.3.1 Sense Distance Monitoring

The SP calculates the maximum distance that it is capable of detecting obstructions ahead of the train. Environmental conditions or damage to locomotive onboard sensing equipment may result in degradation to the SP's ability to detect obstructions. The SP reduces the sense distance accordingly as sensing capability degrades.

a) The SP shall quantify the maximum distance ahead of the lead locomotive that the SP is capable of sensing OOIs under current external conditions.

b) The SP shall update the sense distance at a minimum rate of SP_TBD109 (1)/second.

c) The SP shall quantify the distance the SP can detect OOIs or COIs that that exceeds the quantified sense distance at a rate less than SP_TBD110 instances per hour.

4.1.4.3.2 Degraded Performance Monitoring

The SP continually self-monitors its performance to determine whether the system and/or individual sensors are operating in a degraded state. Such degraded performance may result in reducing the SP ability to provide high confidence, actionable data to ATO Ex. When the SP determines that an individual sensor, or the system as a whole, is operating with degraded performance, the SP populates the "Degraded Performance" field in the ATO SP to ATO Ex Status (Q700) message with the appropriate value. When individual sensors fail, the SP populates the "Sensor Failure" field in the ATO SP to ATO Ex Status (Q700) message with the appropriate number(s) of sensor(s) failed.

a) The SP shall continually monitor the data validity of the sensor data to detect degradation of SP performance.

b) The SP shall send an ATO Ex Status (Q700) message to ATO Ex indicating the SP system is operating with degraded performance.

4.1.4.4 Active State to Standby State Transition Criteria

The SP transitions from the Active state to the Standby state when any of the following have been satisfied:

- SP verifies that the most recent SP_TBD111 (5) valid ATO Ex to ATO SP Status (Q600) message received has a "state" field = "Pre-Arm Setup"
- SP verifies that the most recent SP_TBD112 (5) valid ATO Ex to ATO SP Status (Q600) message received has a "state" field = "Failed"
- If the SP fails to receive a valid ATO Ex to ATO SP Status (Q600) message for SP_TBD113 (5) minutes after the previously received valid ATO Ex to ATO SP Status (Q600) message

  a) *The SP shall transition from the Active state to Standby state if:*

     I. *The most recent SP_TBD111 (5) valid ATO Ex to ATO SP Status (Q600) message received has a "state" field = "Pre-Arm Setup"*

     II. *The most recent SP_TBD112 (5) valid ATO Ex to ATO SP Status (Q600) message received has a "state" field = " Failed"*

     III. *The SP fails to receive a valid ATO Ex to ATO SP Status (Q600) message for SP_TBD113 (5) seconds after the previously received valid ATO Ex to ATO SP Status (Q600) message*

4.1.4.5 Active State to Failed State Transition Criteria

The SP transitions to a failed state when a SP hardware or SP software failure is detected.

a) *Upon detection of a SP hardware failure in the Active state, the SP shall transition to the Failed state.*

b) *Upon detection of a SP software failure in the Active state, the SP shall transition to the Failed state.*

4.1.4.6 Failed State

State in which the SP has detected a failure and is no longer capable of providing ATO Ex with actionable data. The SP transitions from the Active state to the Failed state if SP detects a hardware or software failure. The Failed state is only available after successful completion of the boot-up process; the SP cannot transition to the Failed state beforehand. Prior to completion of the boot-up process, the SP aborts when a failure is detected as defined in Sections 4.1.2.4, 4.1.3.4, and 4.1.4.5.

a) *The SP shall display an external indicator signifying that SP has failed.*

b) *The SP shall record failures resulting in a transition to the Failed state in the event log.*

5. ATO SP External Interface Requirements

5.1 ATO SP Interfaces

Interface Requirements are further specified in an Interface Requirements Specifications (IRS) document, ATO Ex to Sensor Platform Interface Requirements Specification (IRS - ATO Ex to ATO SP). Figure A12 shows known SP interfaces.

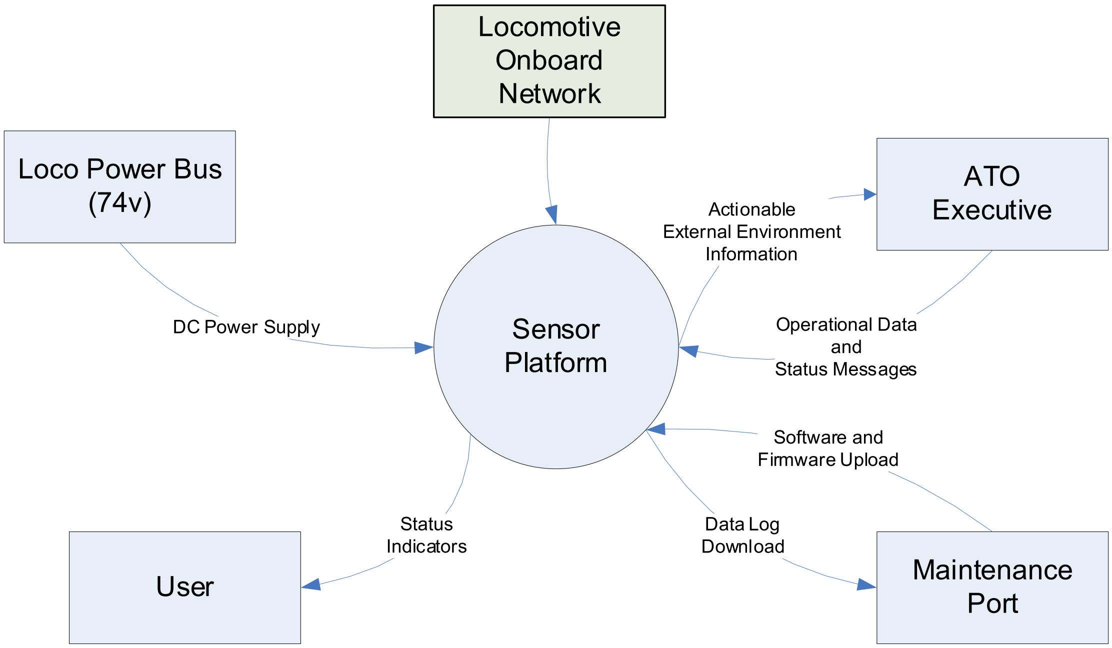

Figure A12. SP Interface Diagram

5.1.1 Human Machine Interface (HMI)

In the context of the SP, the SP provides a visual display that indicates:

- SP power status (on/off)
- SP initialization progress
- Presence of a detected error or fault
- SP operating state (i.e., Active, Standby, Failed, etc.)

a) *The SP shall provide an external indicator signifying that power is applied to SP.*

b) *The SP shall provide an external indicator signifying that SP is in the Initialization state.*

c) *The SP shall provide an external indicator signifying that SP is in the Standby state.*

d) *The SP shall provide an external indicator signifying that SP is in the Active state.*

e) *The SP shall provide an external indicator signifying that SP is in the Failed state.*

f) *The SP shall provide an external indicator signifying SP HW integrity self-test failure.*

g) *The SP shall provide an external indicator signifying SP FW integrity self-test failure.*

h) *The SP shall provide an external indicator signifying SP OS integrity self-test failure.*

i) *The SP indicators shall be visible to onboard railroad personnel.*

5.1.2 ATO SP Locomotive Power Interface

The interoperable SP locomotive power interface accepts power from the 74Vdc locomotive power bus as specified in the MSRP S-9401.V1.0, Section 5. Appropriate power connectors are defined in S-9101, Appendix C, Section 2.0.

Note: Power cabling requirements are not included here. They can be found in:

- *AAR MSRP, Section M, Wiring and Cable Specification, Recommended Practice RP-585*
- *AAR MSRP, Section M, Wire and Cable Insulating Material—Moisture-Resisting Jacketed, Recommended Practice RP-586*
- *AAR MSRP, Wire and Cable Insulating Material—Silicone Rubber Insulated, Recommended Practice RP-587*
- *AAR MSRP, Wire and Cable Insulating Material, Recommended Practice RP-588*

  a) *The SP locomotive power interface shall accept power from 74 VDC locomotive power source.*

  b) *The SP internal power supply, if any, shall conform with the requirements defined in S-9401, Section 5 "Power Supply – Power Requirements."*

  c) *The SP input power connector(s) shall conform with requirements defined in S-9101, Appendix C, Section 2.0 "Other Connectors and Pin Assignments."*

  d) *The SP locomotive power interface shall be controlled by a dedicated circuit breaker located inside the locomotive operator cab.*

5.1.3 ATO Ex Interface

The interoperable SP needs to communicate information regarding identified hazards to the ATO Ex with minimum latency and minimum probability of data loss. To this end, the interoperable SP provides a dedicated high-speed Ethernet interface for communication with the ATO Ex. The SP to ATO Ex interface adheres to the requirements of the MSRP S-9101.V1.0, Appendix A. The ATO Ex – ATO SP IRS includes the requirements that define interoperable SP to ATO Ex messaging protocols.

a) *The interoperable SP shall provide an independent 10 GB Ethernet interface for communication with ATO Ex.*

b) *The interoperable SP to ATO Ex interface shall adhere to MSRP S-9101.V1.0, Appendix A.*

c) *The interoperable SP to ATO Ex interface connector(s) shall conform with requirements defined in S-9101, Appendix C, Section 2.0 "Other Connectors and Pin Assignments."*

5.1.4 Maintenance Port Interface

The SP maintenance port interface design adheres to MSRP S-9101.V1.0 for any standards of physical design, network interface, and any other pertinent design requirements.

a) *The interoperable SP shall provide for an external maintenance port interface.*

b) *The interoperable SP maintenance port interface shall adhere to MSRP S-9101.V1.0, Appendix A.*

c) *The interoperable SP maintenance port interface connector(s) shall conform with requirements defined in S-9101, Appendix C, Section 2.0 "Other Connectors and Pin Assignments."*

5.1.5 Locomotive Onboard Network Interface

The SP functional requirements necessitate an interface with the locomotive onboard network. The SP onboard network interface adheres to any pertinent sections of MSRP S-9101.V1.0.

a) *The interoperable SP shall provide an independent 10 GB Ethernet interface for communication via the locomotive onboard network.*

b) *The interoperable SP locomotive onboard network interface shall adhere to MSRP S-9101.V1.0, Appendix A.*

c) *The interoperable SP locomotive onboard interface connector(s) shall conform with requirements defined in S-9101, Appendix C, Section 2.0 "Other Connectors and Pin Assignments."*

6. System Clock Performance Requirements

The SP system clock maintains time to within SP_TBD114 (1) µs per SP_TBD115 (1) hours. The SP system clock maintains time when power is not applied to the SP.

a) *The SP internal system clock drift shall not exceed SP_TBD114 (1) µs per SP_TBD115 (1) hours.*

b) *The SP internal system clock shall have a maximum departure from the locomotive onboard NTP server of SP_TBD116 (1) seconds.*

c) *The SP internal system clock shall maintain time for a minimum of SP_TBD117 (7) days after power is removed from the SP.*

7. System Effectiveness Requirements

7.1 System Logs

7.1.1 Boot Log

The SP records the results of each integrity check and initialization process conducted during the power-on process for local diagnostic purposes in a boot log. Boot log records can be obtained by railroad personnel using the maintenance port interface defined in Section 5.1.4. Boot logs are maintained for a minimum of SP_TBD0118 (184) days.

a) *The SP shall record the results of each integrity self-test conducted during the power-on process in non-volatile memory.*

b) *The SP shall record the results of the OS initialization process in non-volatile memory.*

c) *The SP shall record the results of the application SW initialization process in non-volatile memory.*

d) *The SP shall store the results of each integrity self-test conducted during the power-on process for SP_TBD0118 (184) days.*

e) *The SP shall store the results of the OS initialization process conducted during the boot-up process for SP_TBD0119 (184) days.*

f) *The SP shall store the results of the application SW initialization process conducted during the boot-up process for SP_TBD120 (184) days.*

7.1.2 Event Log

The SP records system events in an event log. Requirements regarding the generation of event records are found in their respective sections. SP system events recorded in the event log include but are not limited to:

- Successful/failed data and time synchronization (Section 4.1.2.1)
- Application software integrity self-test(s) pass/fail (Section 4.1.2.2.1)
- SP configuration validation (Section 4.1.2.2.1.3)
- Verification of sensor devices (Section 4.1.2.2.1.4)
- Results of sensor device diagnostics (Section 4.1.2.2.1.4)
- Record of ATO Ex state upon receipt of ATO Ex to ATO SP Status (Q600) message (Sections 4.1.3.2.2.5 and 4.1.4.1.2.4)
- SP state transitions

Event log records can be obtained by railroad personnel using the maintenance port interface defined in Section 5.1.4. Event logs are maintained for a minimum of SP_TBD121 (184) days.

a) *The SP shall record all state changes in the event log.*

b) *Upon recording an event to the event log, the SP shall time stamp all records with the time the event occurred.*

c) *The SP shall store the event log results for SP_TBD121 (184) days.*

d) *The SP shall store the event log in non-volatile memory.*

7.1.3 Operational Data Repository

The SP stores operational data (i.e., track and route data, current location data) in no less than two separate non-volatile, independent, and redundant storage locations.

a) *The SP shall maintain no less than two copies of operational data repositories in non-volatile memory.*

b) *The SP operational data repositories shall be physically separate memory devices.*

7.1.4 Sensor Data Log

The SP stores sensor data in a sensor data log. This data is stored for later use or upon request from ATO Ex. The requirements defining the contests of the Sensor Data log are defined in Section 4.1.4.2.7 and includes:

- Raw sensor data
- OOI data
- COI data

  a) *The SP raw sensor data log shall be accessible through the maintenance port.*

  b) *The SP detected OOI data log shall be accessible through the maintenance port.*

  c) *The SP detected COI data log shall be accessible through the maintenance port.*

7.2 SP Algorithm Update

The SP facilitates the ability to update parameters of sensor data analysis algorithms. Learning algorithms are taught offline (i.e., outside of the operational environment) before parameter updates are pushed to active locomotives in operation via an industry standard process. Sensor data collected during ATO operations and stored in system logs is used by the back office to train future generations of learning algorithms.

7.3 Data Integrity

The SP stores data from sensors and sensor data analysis in multiple locations for data integrity and verification. The data stored in these locations is identical. Data is compared and checked for accuracy before use by the SP in every step of the analytics process.

a) *The SP shall provide no less than two non-volatile data storage locations for sensor data.*

b) *The SP sensor data storage locations shall be physically separate.*

c) *The SP shall perform sensor data comparison checks after storing sensor data in physically separate data storage locations.*

d) *The SP shall perform data comparison checks on sensor data before sensor data is utilized in further data analysis.*

e) *The SP shall provide no less than two non-volatile data storage locations for data analysis results.*

f) *The SP data analysis results shall be stored in physically separate locations.*

g) *The SP shall perform data comparison checks after storing data analysis results in physically separate data storage locations.*

h) *The SP shall perform data comparison checks on stored data analysis results before data analysis results are utilized in any further data analysis process.*

i) *The SP shall report an exception condition to ATO Ex when a data comparison check fails.*

8. Extensibility Requirements

The SP processing and memory recourses are allocated in a way that does not risk excessive burden on the system, resulting in potential system faults. Available processing power and available memory space is kept above a limit to ensure proper function of the system.

a) *The SP shall utilize, at most, SP_TBD122 (45) % of the available processing resources.*

b) *The SP shall utilize, at most, SP_TBD123 (35) % of the available memory resources.*

9. Environmental and Physical Requirements

9.1 SP Hardware

The SP components and sensor systems are constructed such that they can withstand the environment in which they are mounted. The SP components may be mounted internally (i.e., locomotive operator cab, component/sensor enclosure, etc.) or externally (i.e., exposed to the outside environment). Regardless of mounting location, the SP component and sensor system functions are not adversely affected by the railroad operational conditions (i.e., high levels of dust, vibration, moisture, heat, etc.).

Note: Cabling requirements are not included here. They can be found in:

- *AAR MSRP, Section M, Wiring and Cable Specification, Recommended Practice RP-585*
- *AAR MSRP, Section M, Wire and Cable Insulating Material—Moisture-Resisting Jacketed, Recommended Practice RP-586*
- *AAR MSRP, Wire and Cable Insulating Material—Silicone Rubber Insulated, Recommended Practice RP-587*
- *AAR MSRP, Wire and Cable Insulating Material, Recommended Practice RP-588*
    - *a) The SP shall conform to the Railroad Electronics Environmental Requirements Standard. S-9401.V1.0.*
    - *b) All locomotive cab-mounted SP components shall comply with AAR MSRP, Section M, Rounding All Possible Exposed Convex Edges and Corners, Recommended Practice RP-5128.*

9.2 Lighting Conditions

The SP performs all functions in all lighting conditions encountered in the operational environment. The SP compensates for rapid changes in light intensity, low light conditions, and high light intensities such that system performance is maintained.

a) The SP performance shall not be degraded by low light conditions of the external environment.

b) The SP performance shall not be degraded by rapid changes in lighting intensity of the external environment.

c) The SP performance shall not be degraded by high lighting intensity of the external environment.

9.3 Environmental Conditions

The SP performs all functions in all weather conditions encountered in the operational environment. The SP compensates for rain, snow, atmospheric haze, and other environmental conditions such that system performance is maintained.

a) *The SP shall compensate for adverse environmental conditions.*

10. Security Requirements

The SP manages data in a secure manner compliant with AAR MSRP Section K-I, Railway Electronics Systems Architecture and Concepts of Operation, Data Protection, Standard S-9010.V1.0. The standards and recommended practices within S-9010 ensure the SP is protected from unauthorized access to railroad proprietary and/or confidential data.

a) *The SP shall conform to AAR MSRP Section K-I, Railway Electronics Systems Architecture and Concepts of Operation, Data Protection, Standard S-9010.V1.0.*

11. Reliability, Availability, and Maintainability (RAM) Requirements

11.1 ATO SP Mean Time Between Failure

a) *The SP shall be designed to achieve a "Basic Reliability" all cause inherent design Mean Time Between Failure (MTBF) of at least SP_TBD124 (X) hours (threshold) and SP_TBD125 (X) hours (objective).*

11.2 Maintenance Port Services

Maintenance port services facilitates any life-cycle maintenance activities to include boot log analysis, software and/or firmware upgrades, and potential periodic sensor and/or system calibration. The maintenance port services are available at any time after a successful power-on process.

a) *The SP maintenance port services shall be available at any time after successful SP power-on.*

b) *SP data logs shall be accessible via the SP maintenance port shall provide access to all SP data logs.*

c) *The SP maintenance port shall provide an interface for SP software updates.*

d) *The SP maintenance port shall provide an interface for SP firmware updates.*

e) *The SP maintenance port shall provide an interface for SP system calibration.*

f) *The SP maintenance port shall provide an interface to monitor SP system performance.*

11.2.1 ITCSM Client

The SP implements Interoperable Train Control System Management (ITCSM) client services in compliance with AAR MSRP Section-V, ITCSM Common Systems Management requirements, Standard S-9451.V1.1. ITCSM services are available in the following states:

- Initialization
- Standby
- Active
- Failed

  a) *The SP shall include ITCSM client services.*

  b) *The ITCSM client services in SP shall comply with AAR MSRP Section-V, ITCSM Common Systems Management requirements, Standard S-9451.V1.1.*

  c) *The SP ITCSM services shall be available in the following states:*

    1) *Initialization*
    2) *Standby*
    3) *Active*
    4) *Failed*

12. Definitions

Term	Definition
0 Speed	Train is stopped and all vehicles in the train are in a quiescent state.
Adjacent Track	An adjacent track is defined as two or more tracks with track centers spaced less than 25 feet apart.
Area of Interest	A specific region of space immediately ahead of or adjacent to the forward path of the train. AOIs include: • Foul Volume • Collision Volume • Right-of-Way • Track and Structure
ATO Onboard Segment	Collection of locomotive onboard systems that make up the overall ATO system, including ITC-PTC onboard, ITC-EMS, LIG/LCCM, sensor platform, ITC-ATO Ex, etc.
Condition of Interest	Conditions within the operating environment that present a potential derailment or damage hazard to the train.
Crossing Gate	A form of active grade crossing warning device designed to inhibit encroachment by physical barriers.
Foul Volume	The Foul Volume is defined as a three-dimensional space along the centerline of track, extending ahead of the train, following the trains intended route, within which objects have a high probability of presenting a hazard to the train.
Foul Volume Clear Distance	The distance from the leading edge of the train to the nearest OOI within the Foul Volume ahead of the train, along the intended route. *Note: In the absence of any OOI's within the Foul Volume, or OOI's on an intercept trajectory, Foul Volume Clear Distance is reported as the farthest distance along the track centerline detectable by the sensor platform, i.e. Foul Volume Sense Distance.*
Foul Volume Sense Distance	Foul Volume Sense Distance is the maximal distance along the centerline of the track along the intended route of the train that the SP can confidently detect objects. *Note: Foul Volume Sense Distance may be affected by track curvature, adverse weather conditions, and natural obstructions such as dense foliage and/or mountainous terrain.*
Fusee	A signaling flare.
Integrity Monitoring	Internal process that verifies the functionality of hardware and/or software
Lead locomotive	The first locomotive in a train.

Term	Definition
Leading Edge of Lead Locomotive	The horizontal plane originating at the Sensor Nodal Point, perpendicular to the track, and limited by the bounds of the Foul Volume.
Object of Interest	An Object of Interest (OOI) is any of the following: 1. An object within the foul volume ahead of a train that presents a collision hazard. 2. An object in the ROW that may move into the foul volume and present a collision hazard to the train. 3. A person or vehicle in the ROW of the track. 4. A railroad appliance the state of which must be observed upon approach by the lead locomotive of a train.
Risk	Per MIL-STD-882E: A combination of the severity of the mishap and the probability that the mishap will occur. Risk is expressed as a probability (a number between 0 and 1) per exposure time (normally 1 hour).
Sense Distance	Sense Distance is the maximal distance that the SP is capable of detecting objects as measured from the leading edge of the lead locomotive. *Note: This is a value that is derived by the Sensor Platform. Sense Distance may be affected by adverse weather conditions and natural obstructions such as dense foliage and/or mountainous terrain.*
Track and Road Structure	The track area includes features of the railroad track such as rail, ties, ballast, and the roadbed. The road structure area includes features that the railroad track traverses such as bridges and tunnels.
Wayside	The area not included in the Foul Volume, i.e., the region of space extending to the left, right, and above the Foul Volume. The extent of the Wayside to the left and right of the Foul Volume is a set, constant value.

Appendix B.
Identified but Undefined Parameters

TBC Parameters:

TBC Index	Description	Assumed Value	Units
SP_TBC01	Width of Foul Volume monitored from either side of track center		feet
SP_TBC02	Height of Foul Volume monitored above roadbed		feet
SP_TBC03	Width of Wayside volume monitored from either side of track center		feet
SP_TBC04	OOI trajectory prediction interval		prob.

TBD Parameters:

TBD Index	Description	Assumed Value	Units
SP_TBD001	Maximum allowable time for SP to complete internal clock synchronization with the locomotive onboard NTP server while in the Initialization state before transitioning to Failed state.		
SP_TBD002	Maximum interval of Integrity Monitoring while in Standby state	60	seconds
SP_TBD003	Minimal rate at which ATO SP shall send an ATO SP Status (Q700) message to ATO Ex while in the Standby state	1	second
SP_TBD004	Maximal time allowed between valid ATO Ex to ATO SP Status (Q600) messages before ATO SP transitions to the Failed state while in the Standby state	5	second
SP_TBD005	Minimal length of time ATO SP will store a record of failure to receive a valid ATO Ex to ATO SP Status (Q600) message within SP_TBD014 (5) seconds while in the Standby state.	184	days
SP_TBD006	Minimal length of time ATO SP will store a record of rejection of an invalid ATO Ex to ATO SP Status (Q600) message while in the Standby state	184	days

TBD Index	Description	Assumed Value	Units
SP_TBD007	Minimal rate of rate ate which ATO SP shall send an ATO SP to ATO Ex Status (Q700) message to ATO Ex while in the Active state.	1	seconds
SP_TBD008	Maximum time allowed between valid ATO Ex to ATO SP Status (Q600) messages before ATO SP transitions to the Failed state while in the Active state	5	seconds
SP_TBD009	Rate at which SP receives the Current Position (Q610) message from ATO Ex.	1	seconds
SP_TBD010	Maximum distance traveled by train before receiving next Current Position (Q610) message from ATO Ex.	100	feet
SP_TBD011	Maximum error in calculating train's footage offset into a track segment.	1	feet
SP_TBD012	Maximum distance traveled by train before SP calculates the train's footage offset into a track segment	100	feet
SP_TBD013	Maximum time allowed between valid Current Position (Q610) messages before SP transitions from Active state to Failed state.	5	seconds
SP_TBD014	Interval at which SP receives train route data from ATO Ex.	30	seconds
SP_TBD015	Maximum time allowed between valid Train Route (Q625) messages before ATO SP transitions to the Failed state while in the Active state	60	seconds
SP_TBD016	Minimum rate at which the SP quantifies ambient external temperature.	1	1/minute
SP_TBD017	Maximum allowable error in ambient external temperature readings	2	degrees Fahrenheit
SP_TBD018	Minimal monitoring capability of the Foul Volume	4,000	ft.
SP_TBD019	Rate at which SP calculates Foul Volume sense distance.	1	1/second
SP_TBD020	Maximal error in Foul Volume Sense Distance calculation	5	%
SP_TBD021	Minimum height above roadbed of OOI that ATO SP must detect within the Foul Volume	12	inches
SP_TBD022	Minimum width of OOI that ATO SP must detect within the Foul Volume	12	inches
SP_TBD023	Minimum length of OOI that ATO SP must detect within the Foul Volume	12	inches

TBD Index	Description	Assumed Value	Units
SP_TBD024	Maximal missed OOI detection rate within the Foul Volume		event/hr.
SP_TBD025	Maximal false OOI detection rate within the Foul Volume		event/hr.
SP_TBD026	Minimum precision of object detection in Foul Volume		
SP_TBD027	Minimum recall of object detection in Foul Volume		
SP_TBD028	Maximum time SP takes to detect OOI after it enters the Foul Volume	1	second
SP_TBD029	Maximum error in quantifying distance from leading edge of train to detected OOIs per 1000ft within the Foul Volume	1	feet
SP_TBD030	Minimal rate at which OOI list is updated	1	seconds
SP_TBD031	Minimal time allowed to assign a detected OOI a unique identifier within the Wayside	1	seconds
SP_TBD032	Minimal rate of AOI indicator update	1	1/sec.
SP_TBD033	Minimal rate of calculated distance to detected OOI update	1	1/sec.
SP_TBD034	Time after which OOI is removed if not detected	30	sec.
SP_TBD035	Maximal false "Non-Hazard" classification to a "Person" within the Foul Volume		event/hr.
SP_TBD036	Maximal false "Non-Hazard" classification to a "Vehicle" within the Foul Volume		event/hr.
SP_TBD037	Maximal false "Non-Hazard" classification to a "Rolling Stock" within the Foul Volume		event/hr.
SP_TBD038	Maximal false "Non-Hazard" classification to a "Unknown" within the Foul Volume		event/hr.
SP_TBD039	Maximal false "Non-Hazard" classification to a "Livestock" within the Foul Volume		event/hr.
SP_TBD040	Maximum error in quantifying clear distance per 1,000 ft	1	feet
SP_TBD041	Minimal rate of clear distance update	1	1/second
SP_TBD042	Collision volume dimension ahead of train	6	ft.
SP_TBD043	Minimal train speed before a collision is assumed	0	mph

TBD Index	Description	Assumed Value	Units
SP_TBD044	Maximal rate of failed collision detection		event/hr.
SP_TBD045	Maximal rate of false collision detection		event/hr.
SP_TBD046	Minimum height of OOI that ATO SP must detect within the Wayside	12	inches
SP_TBD047	Minimum width of OOI that ATO SP must detect within the Wayside	12	inches
SP_TBD048	Minimum length of OOI that ATO SP must detect within the Wayside	12	inches
SP_TBD049	Minimum OOI detection range, function of train speed	4,000	ft.
SP_TBD050	Maximal train speed for OOI detection range	20	mph
SP_TBD051	Maximal missed OOI detection rate within the Wayside		event/hr.
SP_TBD052	Maximal false OOI detection rate within the Wayside		event/hr.
SP_TBD053	Minimum precision of object detection within the Wayside		
SP_TBD054	Minimum recall of object detection within the Wayside		
SP_TBD055	Maximum time SP takes to detect OOI after it enters the SP FOV	1	second
SP_TBD056	Maximum error in quantifying distance from leading edge of train to detected OOIs per 1,000 ft within the wayside	1	feet
SP_TBD057	Maximal false “Non-Hazard” classification to a “Person” within the Wayside		event/hr.
SP_TBD058	Maximal false “Non-Hazard” classification to a “Vehicle” within the Wayside		event/hr.
SP_TBD059	Maximal false “Non-Hazard” classification to a “Rolling Stock” within the Wayside		event/hr.
SP_TBD060	Maximal false “Non-Hazard” classification to a “Unknown” within the Wayside		event/hr.
SP_TBD061	Maximal false “Non-Hazard” classification to a “Livestock” within the Wayside		event/hr.
SP_TBD062	Minimal update rate Potential Intercept indicator for each OOI	1	1/sec.
SP_TBD063	Minimal update rate of Potential Intercept Distance for each OOI	1	1/sec.

TBD Index	Description	Assumed Value	Units
SP_TBD064	Maximal rate of failed Crossing Protection Activation Verification Classification		event/hr.
SP_TBD065	Maximal rate of false Crossing Protection Activation Verification Classification		event/hr.
SP_TBD066	Maximal rate of switch position misclassification		event/hr.
SP_TBD067	Maximal train speed for switch position classification	20	mph
SP_TBD068	Minimal train distance from switch for position classification	150	ft.
SP_TBD069	Maximal error in fusee distance calculation	5	%
SP_TBD070	Minimal update rate of fusee distance calculation	1	1/sec.
SP_TBD071	Maximal rate of failed fusee detection		event/hr.
SP_TBD072	Maximal rate of false fusee detection		event/hr.
SP_TBD073	Maximal error in calculation of distance to unsupported ties	5	%
SP_TBD074	Minimal update rate of distance to unsupported ties	1	1/sec.
SP_TBD075	Maximal rate of failed detection of unsupported ties		event/hr.
SP_TBD076	Maximal error in calculation of deviated Track Curvature	5	Degrees of curvature
SP_TBD077	Maximal error in calculation of distance to deviated Track Curvature	5	Feet per 1,000 feet
SP_TBD078	Minimal update rate of distance to deviated Track Curvature	1	1/sec.
SP_TBD079	Maximal rate of failed detection of deviated Track Curvature		event/hr.
SP_TBD080	Maximal error in calculation of deviated Track Grade	5	%
SP_TBD081	Maximal error in calculation of distance to deviated Track Grade	5	%
SP_TBD082	Minimal update rate of distance to deviated Track Grade	1	1/sec.
SP_TBD083	Maximal rate of failed detection of deviated Track Grade		event/hr.
SP_TBD084	Track gage as measured between gage face of each rail	57.5	in.
SP_TBD085	Maximal train speed to detect excessive track gage	20	mph
SP_TBD086	Minimal distance ahead of train to detect excessive track gage	4,000	ft.

TBD Index	Description	Assumed Value	Units
SP_TBD087	Minimal update rate of distance to excessive track gage	1	1/sec.
SP_TBD088	Maximal rate of failed detection of excessive track gage		event/hr.
SP_TBD089	Maximal error in calculation of distance to water above rail	5	%
SP_TBD090	Maximal error in calculation of distance water is above rail	5	%
SP_TBD091	Minimal update rate of distance to water above rail	1	1/sec.
SP_TBD092	Maximal rate of failed detection of water above rail		event/hr.
SP_TBD093	Maximal error in calculation of distance to snow above rail	5	%
SP_TBD095	Minimal update rate of distance to snow above rail	1	1/sec.
SP_TBD096	Maximal rate of failed detection of snow above rail		event/hr.
SP_TBD097	Maximal error in calculation of distance to rock/earth above rail	5	%
SP_TBD098	Maximal error in calculation of distance rock/earth is above rail	5	%
SP_TBD099	Minimal update rate of distance to rock/earth above rail	1	1/sec.
SP_TBD100	Maximal rate of failed detection of rock/earth above rail		event/hr.
SP_TBD101	Maximal error in calculation of distance to detected fire	5	%
SP_TBD102	Maximal error in calculation of length of detected fire	5	%
SP_TBD103	Minimal update rate of distance to detected fire	1	1/sec.
SP_TBD104	Minimal update rate of length of detected fire	1	1/sec.
SP_TBD105	Maximal rate of failed detection of fire		event/hr.
SP_TBD106	Recorded raw sensor data for later use	24	hours
SP_TBD107	Recorded detected OOI data for later use	24	hours
SP_TBD108	Maximum interval of Integrity Monitoring while in Active State	60	seconds
SP_TBD109	Minimal rate of sense distance update	1	1/second
SP_TBD110	Maximal rate sense distance is reported in excess of actual distance SP is capable of detecting OOIs or COIs		event/hr.

TBD Index	Description	Assumed Value	Units
SP_TBD111	Number of most recently received valid ATO Ex to ATO SP Status (Q600) messages with "state" field = "Pre-Arm Setup" causing ATO SP to transition to Standby state while in the Active state	5	
SP_TBD112	Number of most recently received valid ATO Ex to ATO SP Status (Q600) messages with "state" field = "Failed" causing ATO SP to transition to Standby state while in the Active state	5	
SP_TBD113	Maximal time allowed between valid ATO Ex to ATO SP Status (Q600) message that allows for ATO SP transition from Active state to Standby state	5	minutes
SP_TBD114	Time SP internal clock drift shall not exceed per given timeframe	1	µs
SP_TBD115	Timeframe of SP internal clock drift	1	hours
SP_TBD116	Maximum departure of SP internal system clock from the locomotive onboard NTP server	1	seconds
SP_TBD117	Minimum time SP internal system clock maintains time after power is removed from SP	7	days
SP_TBD118	Recorded boot log results stored for later use	184	days
SP_TBD119	Recorded OS initialization process results stored for later use	184	days
SP_TBD120	Recorded application SW initialization process results recorded for later use	184	days
SP_TBD121	Recorded error log results stored for later use	184	days
SP_TBD122	Maximum SP utilization of processing resources	45	%
SP_TBD123	Maximum SP utilization of memory resources	35	%
SP_TBD124	Minimum all cause inherent Mean Time Between Failure		hr.
SP_TBD125	Objective all cause inherent Mean Time Between Failure		hr.